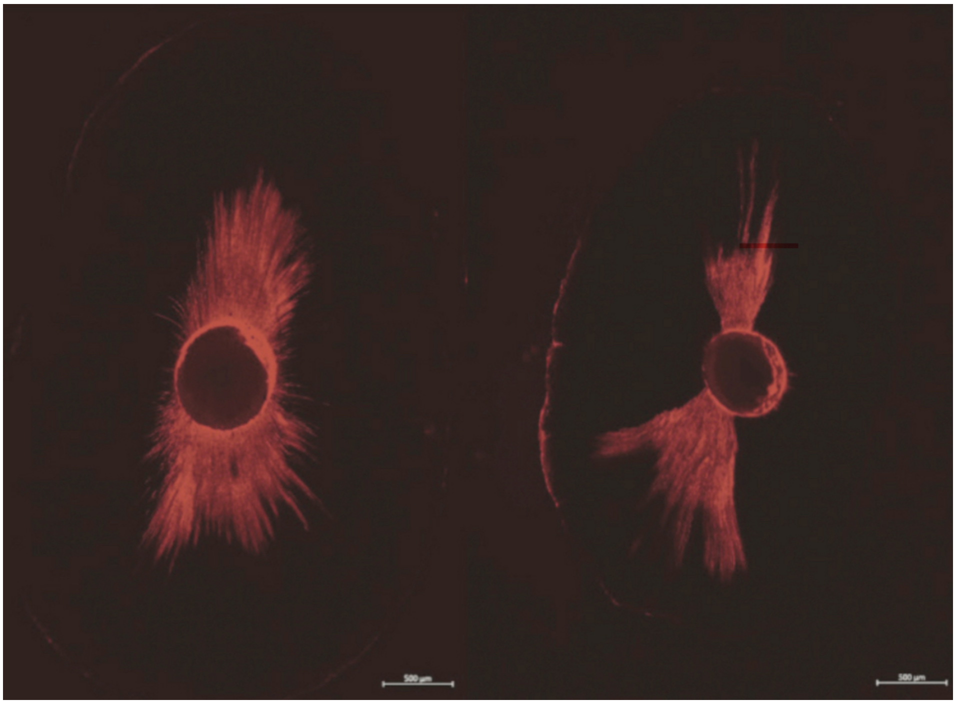
VOLUME: 9 ISSUE: 2 YEAR: 2024

TURKISH ENDODONTIC JOURNAL

E-ISSN 2459-1726



The official Journal of Turkish Endodontic Society

e-ISSN 2459-1726

Contact:

Address: Mevlanakapı Mah. Turgüt Özal Cad. Kemikliburun Sok. Nesrin Apt. No: 1A, Şehremini, İstanbul
Tel: +90 212 621 34 49 Fax: +90 212 621 34 50
Correspondence: +90 216 550 61 11 (Kare Publishing)

Publisher

KARE

Göztepe Mah., Fahrettin Kerim Gökay Cad., No: 200 Da: 2, Göztepe, Kadıköy, İstanbul
Phone: +90-216-550 61 11 Fax: +90-216-550 61 12
e-mail: kare@karepb.com Web: www.karepb.com

INFORMATION FOR THE AUTHORS

1. Aims and Scope

Turkish Endodontic Journal (TEJ) is the official scientific publication of Turkish Endodontic Society and open access, peer-reviewed international journal. TEJ is published three times per year (May, August, December). The authors are invited to submit original scientific articles, case reports, review articles regarding endodontology and dental traumatology. Letter to the Editor section is also available for authors to write a comment letter on a previously published article in the journal.

TEJ does not charge authors or authors' institutions to submit, process or publish articles. There is no fee for extra pages or color images.

2. Editorial Policies and Ethical Considerations

The acceptance criteria for all articles are the article's quality, originality and its significance to our readership. Except where otherwise stated, manuscripts are peer-reviewed by two anonymous reviewers and the Editor. The final decision is given by the Editorial Board, which reserves the right to refuse any material for publication.

Manuscripts should be written in a clear, concise, direct style. Editor-in-Chief or the Editorial Board reserves the right to change the format, grammar, or sentence structure of any part of the manuscript to comply with the guidelines to fit the standard format and journal style.

Authorship

TEJ strictly adheres to the International Committee of Medical Journal Editors (ICMJE) standards to define the authorship qualifications. We recommend that an author should provide ALL of the following four criteria:

(1) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work;

(2) Drafting the work or revising it critically for important intellectual content;

(3) Final approval of the version to be published;

(4) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Contributors who do not qualify as authors should be mentioned under 'Acknowledgements'.

Authors should take collective responsibility for their work and the content of their publications. Corresponding author should submit Authors Contribution Form before proceeding with further submission and evaluation processes.

Declaration of Artificial Intelligence (AI)–Assisted Technology in Scientific Writing

At submission, authors should disclose whether they used artificial intelligence (AI)– assisted technologies (such as Large Language Models [LLMs], chatbots, or image creators) in the production of submitted work. Authors who use such technology should describe, in both the Title Page and the submitted work, how they used it. Chatbots (such as ChatGPT) and AI assisted technologies should not be listed as an author or co-author nor cited because they cannot be responsible for the accuracy, integrity, and originality of the work, and these responsibilities are required for authorship. Therefore, humans are responsible for any submitted material that included the use of AI-assisted technologies. Authors should carefully review and edit the result because AI can generate authoritative-sounding output that can be incorrect, incomplete, or biased. Authors should be able to assert that there is no plagiarism in their paper, including in text and images produced by the AI. Humans must ensure there is appropriate attribution of all quoted material, including full citations.

Disclosure Statement

Authors must declare any financial support or relationships that may pose a conflict of interest by disclosing any financial arrangements they have with a company whose product figures prominently in the submitted manuscript or with a company making a competing product, or any conflict relating to technology or methodology. The absence of any interest to disclose must also be stated.

Standards

All submissions should comply with the ICMJE Uniform requirements. Submission of checklists and flow charts of Preferred Reporting Items for Study Designs in Endodontics (PRIDE) requirements are mandatory before proceeding the article processing for case reports (PRICE), animal studies (PRIASE), randomised clinical trials (PRIRATE), laboratory studies (PRILE). Systematic reviews and meta analysis should comply with Transparent reporting of systematic reviews and meta-analysis (PRISMA). Observational studies should comply with Strengthening the reporting of observational studies in epidemiology (STROBE). Diagnostic accuracy studies should comply with Essential Items for Reporting Diagnostic Accuracy Studies (STARD). All relevant and required checklists and flow charts can be found at: https://turkishendodonticjournal.com/Forms

Disclaimer and Copyright

Submission of a manuscript implies that the work described has not been published before; that it is not under consideration for publication anywhere else entirely or partially, nor will it be submitted for consideration of publication anywhere else until a final publication decision concerning this manuscript has been made by the Editor(s) of the Journal; that its publication has been approved by all co-authors, if any, as well as by the responsible authorities at the institute where the work has been carried out. The publisher cannot be held legally responsible should there be any compensation claims.

Copyright of open access article is retained by the author(s). Turkish Endodontic Journal provides free access and allows free download of its contents from the journal's website (https://turkishendodonticjournal.com/default.aspx). Both anonymous or registered users can read and/or download articles for personal use. The material cannot be used for commercial purposes. The license does not give the user all permissions necessary for his/her intended use. For example, other rights such as publicity, privacy, or moral rights may limit how the material can be used.

Articles published in this journal are available for use by researchers and other readers without permission from the author or the publisher provided that the author and the original source are cited. The responsibility of the content(s) and/or opinion(s) provided in the articles which are published in the print and/or online versions of the journal, belong exclusively to their respective author(s). The publisher/editor/editorial board/reviewers cannot be held responsible for errors, scientific or otherwise, in the contents or any consequences arising from using the information contained therein. The opinions expressed in the articles published in this journal are purely those of their respective authors and in no way represent the opinions of the publisher/editor/editorial board/reviewers of the journal.

Publication Ethics and Avoiding Allegations of Plagiarism

Please refer to TEJ Publication Ethics and Publication Malpractice Statement. By submitting their manuscripts to TEJ, authors also accept that their manuscripts may be screened for signs of plagiarism using any means necessary and available; including, but not limited to, the use of plagiarism detection software.

Ethical Approvals

Experimentation involving human subjects should be conducted in full accordance with the Helsinki Declaration of World Medical Association (http://www.wma.net/en/30publications/10policies/b3/index.html) and legal requirements of the country where the research had been carried out. The manuscript must include a statement indicating that informed consent was obtained from all participants. A statement confirming that the study has been reviewed and approved by an ethical or advisory board with the approval number and board name should also be included. The patient's privacy should not be violated. Identifying information such as names, initials, hospital numbers, unnecessary details in photographs should be omitted from the submission. When detailed descriptions, photographs and/or videos of faces or identifiable body parts that might permit a patient to be identified must be included in the submission, authors must obtain written informed consent for its publication from the patient or his/her parent/guardian.

Experiments on laboratory animals must comply with the Guidelines of the European Communities Council Directive 2010/63/EU and with local laws and regulations. A statement confirming that the study has been reviewed and approved by an ethical or advisory board should also be included (http://www.eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32010L0063).

Data Sharing and Accessibility

The journal encourages authors to share the data and other artifacts supporting the results in the paper by archiving it in an appropriate public repository. Authors may include a data accessibility statement, including a link to the repository they have used, in order that this statement can be published alongside their paper.

3. Submissions

Note that submission implies that the content has not been published or submitted for publication elsewhere except as a brief abstract in the proceedings of a scientific meeting or symposium. Once you have prepared your submission following the Guidelines, manuscripts should be submitted online at https://jag.journalagent.com/tej/?plng=eng.

Authors must declare any financial support or relationships that may pose a conflict of interest (see 'Disclosure Statement' above).

Two mandatory word-files prepared using Microsoft Word need to be included upon submission: A title page, the main text file that includes all parts of the text in the sequence indicated in the section 'Parts of the manuscript', including figure legends but the tables and figures should be supplied separately. The main text file should be prepared using Microsoft Word, double-spaced and should not contain author name(s), affiliation(s) or information(s) regarding their identity to ensure blind review.

Each figure should be supplied as a separate file, with the figure number incorporated in the file name. For submission, figures with 300 d.p.i. saved as .jpg or .bmp files should be uploaded.

The submission system will prompt you to use an ORCiD (a unique author identifier) to help distinguish your work from that of other researchers.

An optional cover letter may be included; the text can be entered directly into the field "Message to the Editor" or uploaded as a separate file.

Submission Forms

Authors who are willing to submit their manuscripts to TEJ are required to complete and sign the Copyright Transfer Form. Please send these forms electronically when submitting your manuscript. Article evaluation process cannot be started until all documents are received.

4. Manuscript Categories and Requirements

Original Research - reports of new research findings or conceptual analyses that make a significant contribution to the current knowledge (3500 word limit). The relevant checklist must be provided in the submission documents.

Literature Reviews - critical reviews of the literature, including systematic reviews and meta-analyses (5000 word limit).

Case Reports / Series – reports of the diagnosis and/or the management of patient(s) with unusual observations of novel cases, diseases, therapeutic approaches with significant contribution to knowledge (3000 word limit). Case reports / series should be reported in full accordance with the guidelines of PRIDE. The PRICE checklist must be provided in the submission documents.

Letters to the Editor - are welcomed (1000 word limit).

Clinical Trials

Randomized controlled clinical trials should be reported in full accordance with the guidelines of PRIDE. The PRIRATE checklist must be provided in the submission documents. Following free public clinical registries can be used to register clinical trials. Registration number and project name will be published in the article.

Systematic reviews & meta analysis – should comply with Transparent reporting of systematic reviews and meta-analysis (PRISMA) (6000 word limit). The PRISMA checklist must be provided in the submission documents.

DNA Sequences and Crystallographic Structure Determinations

Manuscripts reporting protein or DNA sequences and crystallographic structure should provide Genbank or Brookhaven Protein Data Bank accession numbers, respectively.

5. Manuscript preparation

Language

Authors should write their manuscripts in US English. Spelling and phrasing should conform to standard usage and be consistent throughout the paper. Authors whose native language is not English are encouraged to consult with a native speaker or to collaborate with a colleague whose English skills are more advanced. Authors may also use professional translation services at their own expense. Please note that using language editing services does not imply that the article will be selected for peer-review or be accepted by TEJ.

Style and Format

Use A4 page format in Microsoft Word software, normal margins (top & bottom & left & right 2.5 cm), Times New Roman Font, Font size 12, double line spacing for main text and single line spacing for "References" section. US English grammar check option should be enabled. Words and abbreviations in Latin should be written in italics: "et al., in vivo, in vitro, in utero, in situ, ad libitum, clostridium perfringens, Staphylococcus aureus".

Units

Abbreviations used for units, prefixes, and symbols should comply with the International System of Units (SI) (http://physics.nist.gov/Pubs/SP330/sp330.pdf). If this is not possible, SI equivalents must be presented between parentheses. The complete names of individual teeth must be given in the main text (e.g., maxillary right central incisor). FDI 2-digit system should be used in table and figure legends (e.g., 11 for maxillary right central incisor).

Abbreviations

Abbreviations should be used sparingly – only where they ease the reader's task by reducing repetition of long, technical terms. Initially, use the word in full, followed by the abbreviation in parentheses. After that, use the abbreviation only.

Trade Names

Chemical substances should be referred to by the generic name only. Trade names should not be used. Drugs should be referred to by their generic names. If proprietary drugs have been used in the study, refer to these by their generic name, mentioning the proprietary name, and the manufacturer's name and location in parentheses.

Parts of the Manuscript

The manuscript should be submitted in separate files: (A) Title page; (B) Main text file; (C) Figures.

A. Title Page

Main title of the manuscript should be written in Times New Roman font, in bold capital letters of 12 font size. A running title with no more than 50 characters (including spaces) written in lower case letters must also be provided below the main title. Names, surnames and affiliations of all authors should appear below the running title. Use superscript numbers "1,2,3" for authors from different institutions, do not use any numbers if all authors are from the same department.

Name, surname, postal address, phone, fax and email of the corresponding author should be mentioned separately. If the paper has been previously presented in a scientific meeting either as an oral presentation or as a poster presentation, the title of the manuscript should be followed by an asterisk (*), which refers to a footnote indicating the name of the organization, location and date of its presentation.

The present address of any author, if different from that where the work was carried out, should be supplied in a footnote.

Please upload the title page as separate under the files section during submission.

Authors should disclose whether they used artificial intelligence (AI)– assisted technologies (such as Large Language Models [LLMs], chatbots, or image creators) in the production of submitted work. Authors should assert that there is no plagiarism in their paper, including in text and images produced by the AI -if any- and must ensure there is appropriate attribution of all quoted material, including full citations.

B. Main Text File Order

Manuscripts should be presented in the following order: (I) title, abstract and keywords, (II) text, (III) disclosure, ethical approval, funding and acknowledgments statements and (IV) references, (V) figure legends (VI) tables.

I. Abstract & Keywords Page

This page should start with the main title of your manuscript. It should not contain author names, affiliations or any citations. This section must describe the main objective(s) of the study, and explain how the study was conducted without giving too much methodological detail and summarize the most important results and their significance. It should be as clear and concise as possible. Start numbering from this page and place it at the lower right-hand corner of the page footer. Abstracts should not exceed 200 words for original research papers and should be structured to include Purpose, Methods, Results, Conclusion headings written in bold letters.

Abstracts of case reports and review articles are limited to 200 words and should be unstructured.

A maximum of five keywords should follow the abstract, preferably chosen from the Medical Subject Headings (MESH) terms (http://www.ncbi.nlm.nih.gov/mesh). Keywords should be listed alphabetically and separated with a comma.

II. Text

Original research articles

Authors should use the following subheadings to divide the sections of their original research manuscript: Introduction, Materials and Methods, Results and Discussion.

Introduction should provide a concise account of the research problem and introduce the reader to the pertinent literature. The gap in the literature and study objective(s) and/or hypothesis should be clearly stated in the last paragraph.

Materials and Methods section should describe the study population/sample or specimens, the variables, and the study procedures with sufficient detail to ensure reproducibility. Include ethical approvals for clinical trials and animal studies in the first paragraph of this section. Provide the name of the responsible organization, year of approval and project number. Authors may use sub-headings to increase the readability such as "specimen collection", "micro-ct analysis" or "statistical analysis". These sub-headings should be written in italic letters. Statistical methods, and analysis should be mentioned.

Results should be written clearly without subjective interpretation and be supported with tables and figures when necessary. Text should complement any figures or tables but it should not repeat the same information. When reporting your findings, follow the same order you have used in "Materials and Methods" section.

Use a maximum of two digits after the decimal point.

Provide the relation of p values with the selected threshold between parentheses at the end of the sentence before the period. Such as; $p > .05$ or $p < .0001$.

Discussion section state major findings, their meanings and clinical relevance, present any contrasts with the results of similar studies, describe unavoidable limitations in the study design and make suggestions for further research within the limits of their data.

Conclusion should be supported by results and must be consistent with the objectives of the research.

Case Reports/Series

The main text is divided into these subheadings: introduction, case report (or series), and discussion.

Narrative or Systematic Reviews and Meta-Analyses

The manuscripts should summarize the current state of understanding on a particularly important topic in dentistry based on previously published data, preferably written by authoritative figures of that field. A minimum of 50 references must be cited. Authors may use their selected headings between Introduction and Conclusion sections.

Systematic review or a meta-analysis include the same manuscript design as for the original research articles.

Letter to the Editor

Letters to the Editor are short articles in which readers can share their opinions and comment on articles published in the journal. Authors should cite the article to which they are referring. Letters will be evaluated by the Editor-in-Chief and, if accepted for publication, the author(s) of the original paper will be invited to submit a reply.

In-text Citations

TEJ recommends that in-text citations be numbered consecutively in the order of appearance with Arabic numerals between parentheses and appear in front of the full point or comma at the end of the sentence/clause. References should be numbered consecutively in the order in which they appear in the text.

If cited in tables or figure legends, number according to the first identification of the table or figure in the text.

III. Disclosure, Ethical Approval, Funding and Acknowledgments Statements

Acknowledgments

This section is optional. Authors must acknowledge all individuals who do not fulfill the requirements for authorship but who had contributed to the preparation of the manuscript by assisting in writing, literature search, data analysis and/or supply of materials.

Source of Funding

This section is mandatory. Financial support from any institutional, private or corporate sources must be disclosed. Clearly state the name of the funding organization, year and the project number. If there is no source of funding declaration to make, please declare.

Conflict of Interest

This section is mandatory. Any financial or personal activities (royalties, grants, consultancy fee, patent registration, ownership, employment) that could be perceived as potential conflicts of interests must also be disclosed. If the author has no declaration to make, please declare "Authors declare any conflict of interest" or "None declared".

Ethical Approval

Manuscripts must contain a statement that all human/animal studies have been reviewed by the appropriate ethics committee providing approval number, year and committee name. If there is no human/animal subject involve, please write "Not applicable".

Informed Consent

All investigations on human subjects must include a statement that the subject gave informed consent. If there is no human subject involve, please write "Not applicable".

IV. References

Authors are responsible for the accuracy of the references.

Cite all authors' names when there are six or fewer; when seven or more, list the first three followed by et al.

All citations mentioned in the text, tables or figures must be listed in the reference list.

Names of journals should be abbreviated in the style used in Index Medicus.

References should be listed in the following form:

Journal article:

1. Keskin KO, Parker P. Microbiota of deep caries in permanent dentition. J Endod 2022; 124: 980–3.

Journal Article Electronic Publication Ahead of Print:

2. McKeage K. Tobramycin inhalation powder: a review of its use in the treatment of chronic pseudomonas aeruginosa infection in patients with cystic fibrosis. Drugs 2013; [Epub ahead of print] Available from: http://link.springer.com/article/10.1007%2 Fs40265-013-0141-0

Book:

3. Keskin KO, Parker P. Endodontic microbiology. 2nd ed. Albany, NY: Wiley; 1996.

Chapter in a Book:

4. Keskin C. Root canal irrigants. In: Keleş A, eds. Endodontology: pathophysiology, diagnosis, and management. 2nd ed. New York: Raven Press; 1995. pp. 465–78.

Web page:

5. National Health and Medical Research Council. Clinical practice guidelines for the management of early breast cancer. 2nd ed. [PDF on Internet]. Canberra: Commonwealth of Australia, [updated 6 September 2003; cited 3 March 2004]. Available from: www.nhmrc.gov.au/publiactions/pdfcp74.pdf

Authors are encouraged to use English sources in the references section. However, if it is not possible, they should write the original name of the article in square brackets when using a reference in a different language, provided that it does not constitute the majority of references.

Authors are responsible for sending the full-text versions of any cited paper or textbook and the professional English translation of any non-English paper or textbook as per the request of the editorial board and/or the reviewers.

V. Figure Legends

Legends should be concise but comprehensive – the figure and its legend must be understandable without reference to the text. Include definitions of any symbols used and define/explain all abbreviations and units of measurement.

VI. Tables

Please set table format to custom borders, no vertical lines, no shades, no background colors. Tables should be numbered consecutively with Arabic numerals in the order mentioned in the text.

All tables must be included in the main text of the article followed by figure legends in separate pages. All tables should be self-explanatory. Please provide full explanation for abbreviations even if they are presented in the main text. Legends should be written in Times New Roman and be positioned right above the table.

C. Figures

Figures (photographs, graphs, charts, drawings, pictures, etc.) should be numbered consecutively with Arabic numerals in the order of mention in the text. High-quality pictures with 300 dpi resolution in JPEG JPG, BMP, TIFF, PNG or PSD file formats are generally acceptable for publication. Drawings and shapes should be in vector format.

6. Publication Process after Acceptance

If your paper is accepted, the author identified as the formal corresponding author will receive an email prompting them to log in to Author Services and they will be required to complete a copyright license agreement on behalf of all authors of the paper.

Once the paper has been typeset, the corresponding author will receive an email alert containing proof to be checked and corrected before publication within seven days. It is, therefore, essential that a working email address is provided for the corresponding author. Proofs should be corrected carefully; responsibility for detecting errors lies with the author.

Articles will generally appear in the order in which they were accepted as publication; however, Editor-in-Chief and Editorial Board reserve the right to modify this schedule in the presence of critical scientific issues.

DOI Number

Digital Object Identifier (DOI) number is a unique alphanumeric identifier assigned by a registration agency. Once it is assigned to an article, the DOI will never change; therefore, it is ideal for citing and linking electronic documents. Your article will be assigned a DOI number provided by the CrossRef registration agency.

Correction, Retraction & Removal

A formal correction will be issued in the journal by the Editor-in-Chief if only a small portion of otherwise reliable article is flawed in a way that does not severely affect the findings reported in it (such as mistakes in the spelling of a drug, miscalculation of a formula, mismatch between images and their captions or incorrect author list). Online articles will not be corrected directly. An erratum (for publishing error) or a corrigendum (for author error) will be published in the next issue of the journal.

Articles may be retracted by its authors or by the Editor-in-Chief under the advice of the scientific community. If authors are willing to retract an article before publication(accepted or under review), requests must be sent to the Editor-in-Chief from the corresponding author of the manuscript. This document must include the reason the article should be retracted and written confirmation (email, fax, letter) from all authors that they agree on the retraction. A formal retraction announcement written by the Editor-in-Chief will be published.

Need Assistance?

Please contact editorial office by sending an email to: tej@jag.journalagent.com

Address: Mevlanakapı Mah. Turgüt Özal Cad. Kemikliburun Sok. Nesrin Apt. No: 1A, Şehremini, İstanbul

Tel: +90 212 621 34 49

Fax: +90 212 621 34 50

Publisher: KARE PUBLISHING

Tel: +90 216 550 61 11 Fax: +90 216 550 61 12

E-mail: kareyayincilik@gmail.com

INFORMATION FOR THE REVIEWERS

All submissions to Turkish Endodontic Journal are first reviewed for completeness and only then sent to be assessed by the editorial board who will decide whether they are suitable for peer review. Editorial team members will consider the peer-reviewed reports when making a decision, but are not bound by the opinions or recommendations therein. A concern raised by a single peer reviewer or the editors themself may result in the manuscript being rejected. Authors receive peer review reports with the editorial decision on their manuscript. Peer reviewer selection is critical to the publication process. It is based on many factors, including expertise, conflict of interest and previous performance. Speed, thoroughness, sound reasoning and collegiality are highly desirable. Where an editorial board member is on the author list or has any other competing interest regarding a specific manuscript, another member of the Editorial Board will be assigned to oversee peer review.

Editor(s) are expected to obtain a minimum of two peer reviewers for manuscripts. Peer review reports could be in English or Turkish and provide constructive critical evaluations of the authors' work, particularly in relation to the appropriateness of methods used, whether the results are accurate, and whether the conclusions are supported by the results. Editorial decisions should be based on peer reviewer comments that meet these criteria rather than on recommendations made by short, superficial peer reviewer reports which do not provide a rationale for the recommendations. When making a decision based on one report, editor(s) are expected to only do so if the peer review report meets the required standards. In the rare, exceptional, occasions when two independent peer reviewers cannot be secured, the Editor may act as a second reviewer or make a decision using only one report. Potential peer reviewers should inform the Editor of any possible conflict of interest before accepting an invitation to review a manuscript. Communications between Editors and peer reviewers contain confidential information that should not be shared with third parties.

Peer reviewers should adhere to the principles of COPE's ethical guidelines for peer-reviewers which can be found at the following link: https://publicationethics.org/sites/default/files/ethical-guidelines-peer-reviewers-cope.pdf

Reviewers are asked to respond promptly within the number of days agreed. If reviewers anticipate a delay, they should inform the editorial board to keep the authors informed and, where necessary, find alternatives.

Turkish Endodontic Journal

Volume 9, Number 2, Year 2024

Contents

ORIGINAL ARTICLE

Turk Endod J 2024;9(2):71–76
doi: 10.14744/TEJ.2024.52724

Evaluation of the frequency of dental anomalies in children: A cross-sectional retrospective study

Büşra Karaağaç Eskibağlar,[1] Yelda Polat,[2] Şemsettin Yıldız,[3] Gizem Karagöz Doğan[4]

[1]*Department of Pediatric Dentistry, Fırat University, Elazığ, Türkiye*
[2]*Department of Pediatric Dentistry, Dicle University, Diyarbakır, Türkiye*
[3]*Department of Pediatric Dentistry, Gaziantep University, Gaziantep, Türkiye*
[4]*Department of Pediatric Dentistry, Iğdır University, Iğdır, Türkiye*

Purpose: This study aimed to determine the prevalence of common dental anomalies in children.

Methods: In this study, 5280 digital orthopantomographic images of patients aged 5-16 years were retrospectively analyzed. A total of 3619 digital orthopantomographic images that met the study criteria were evaluated. Descriptive statistics of the categorical data obtained were analyzed using percentage and frequency analyses, followed by Pearson Chi-Square or Fisher's Exact test for binary group comparisons. The significance level for statistical analyses was set at ($p < 0.05$).

Results: In the individuals included in the study, at least one dental anomaly was detected in 13.78%. Numerical anomalies were the most commonly observed type of anomaly, with hypodontia being the anomaly with the highest prevalence in this group. A statistically significant difference was observed between genders in the frequency of supernumerary teeth, ectopy, and mesiodens ($p > 0.05$).

Conclusion: Dental anomalies can occur in different types in humans. Clinicians can prevent future dental problems that may occur in later ages with the early diagnosis and treatment of dental anomalies.

Keywords: Dental anomalies; hypodontia; mesiodens; numerical anomalies; supernumerary teeth.

Introduction

Dental anomalies can be congenital, developmental, or acquired (1). While congenital anomalies have a genetic transmission, developmental anomalies occur during the formation of a tooth or teeth. It is known that acquired anomalies occur after the normal formation of teeth (2). The etiology of dental anomalies is not completely understood. Developmental tooth anomalies arise due to the influence of genetic and environmental factors, particularly during the morpho-differentiation or histo-differentiation stages of tooth development (3). Depending on the effects occurring at different stages of development, various anomalies such as number, structure, size, and shape can be observed (4). Dental anomalies are usually asymptomatic. Common oral diseases, such as tooth decay, can overshadow dental anomalies and may not be detected during clinical practice (5). These anomalies can affect a single tooth or the entire dentition and can appear as part of any systemic disease or syndrome (6). Early diagnosis of

Cite this article as: Karaağaç Eskibağlar B, Polat Y, Yıldız S, Karagöz Doğan G. Evaluation of the frequency of dental anomalies in children: A cross-sectional retrospective study. Turk Endod J 2024;9:71-76.
Correspondence: Büşra Karaağaç Eskibağlar. Fırat University, Elazığ, Türkiye
Tel: +90 424 – 237 00 00 **e-mail:** bkeskibaglar@firat.edu.tr
Submitted: March 11, 2024 **Revised:** March 25, 2024 **Accepted:** April 01, 2024 **Published:** August 29, 2024

dental anomalies is of great importance in the diagnosis and prognosis of genetic anomalies involving the craniofacial region (5). Teeth with anomalies can cause eruption disorders, malocclusion, an increase in caries incidence, and aesthetic problems. Additionally, patients may experience speech and chewing problems, temporomandibular joint pain, and periodontal issues due to increased occlusal force (7,8). Identifying these teeth with an appropriate diagnostic protocol can help in creating an ideal treatment plan that results in less invasive interventions and a more favorable prognosis (9). Dentists can contribute to the diagnosis of such syndromes by detecting these anomalies through clinical and radiographic examination. The aim of this study is to determine the prevalence of the most common dental anomalies that can occur in childhood, thereby providing guidance to clinicians on this subject.

Materials and Methods

This study was conducted in accordance with the guidelines of the Helsinki Declaration on Human Rights and received ethical approval from the Non-Interventional Research Ethics Committee of Fırat University (2024/02-07). In this cross-sectional study, digital orthopantomographic imaging (Planmeca ProMax 3D Mid, Helsinki, Finland) of 5280 patients aged 5-16 who visited the Pediatric Dentistry Department of Firat University Faculty of Dentistry for various reasons between April 2021 and August 2022 was retrospectively evaluated by a single researcher. Of the 5280 digital orthopantomographic images, patients who had undergone dental extraction, had cleft lip and palate, had any syndrome, and had digital orthopantomographic images with poor image quality for evaluation were excluded from the study, and 3619 digital orthopantomographic images were included. Open-source software (Jamovi®) version 1.8 was used for the evaluation of statistical data. After performing percentage and frequency analyses for the descriptive statistics of categorical data, Pearson Chi-Square or Fisher's Exact test was used for the comparison of two groups. A significance level ($p < 0.05$) was accepted for statistical analyses.

Results

In this study, panoramic radiographs of 3619 children aged between 5-16 were evaluated for the presence of dental anomalies. Of the evaluated panoramic radiographs, 42.4% belonged to female patients and 57.6% to male patients. The average age of the individuals in the study group was determined to be 10.8 ± 2.95. The average age for males was 10.5 ± 2.97, while for females, it was 10.9 ± 2.93. Upon examining the individuals in the study group, it was found that 3120 out of 3619 individuals did not have any dental anomalies, while 476 out of 499 individuals had one dental anomaly. Furthermore, 23 individuals had two or more dental anomalies.

According to the data presented in Table 1, the types of dental anomalies detected in the studied population, the number of individuals with these anomalies, and the prevalence of each dental anomaly are shown. According to this data, numerical anomalies constitute the most commonly encountered group of anomalies. Hypodontia, a subcategory of this group, was observed in 46.9% of individuals

Table 1. Detected dental anomaly type, number of individuals with dental anomalies, and prevalence of dental anomalies

Dental Anomaly Type	Number of Individuals with Dental Anomalies	Prevalence of Dental Anomalies (%)
Number of Anomalies	288	57.7
Tooth Deficiency	235	47.1
Hypodontia	234	46.9
Oligodontia	1	0.2
Hyperdontia	53	10.6
Meziodens	34	6.8
Supernumerary	19	3.8
Positional Anomalies	59	11.8
Ectopia	54	10.8
Impacted Tooth	4	0.8
Transposition	1	0.2
Shape Anomalies	175	34.6
Dilaceration	50	10.0
Taurodontism	101	20.2
Peg Lateral	3	0.6
Fusion	2	0.4
Talon Cusp	19	3.8

Table 2. Frequency and percentage distribution of dental anomalies by gender [n(%)]

Dental Anomaly Type	Male	Female	Total	P-Value
Dilaceration	25(5)	25(5)	50	0.177
Taurodontism	44(8.8)	57(11.4)	101	0.570
Peg Lateral	1(0.2)	2(0.4)	3	1.000
Supernumerary	13(2.6)	6(1.2)	19	0.014*
Hypodontia	86(17.2)	148(29.7)	234	0.065
Ectopia	15(3)	39(7.8)	54	0.035*
Mesiodens	20(4)	14(2.8)	34	0.029*
Fusion	1(0.2)	1(0.2)	2	1.000
Impacted Tooth	2(0.4)	2(0.4)	4	1.000
Talon Cusp	8(1.6)	11(2.2)	19	0.926
Oligodontia	1(0.2)	0(0)	1	0.411
Transposition	0(0)	1(0.2)	1	1.000

*Statistically significant p values.

Table 3. Frequency and percentage distribution of the number of dental anomalies by gender [n(%)]

	Male	Female	p-value
Individuals with 1 dental anomaly	196(39.3)	283(56.7)	0.716
Individuals with 2 or more dental anomalies	9(1.8)	11(2.2)	0.818
Total	205(41.1)	294(58.9)	

(n = 234), making it the anomaly type with the highest prevalence among numerical anomalies. The second most prevalent group of anomalies following numerical anomalies is shape anomalies, with taurodontism being the most frequently observed anomaly type in this group with a prevalence of 20.2% (n = 101). The group with the least frequency in the study is positional anomalies, with ectopia being the most commonly encountered anomaly type in this group with a prevalence of 10.8% (n = 54) (Table 1).

Table 2 compares the frequency and percentage distributions of dental anomalies according to gender. Significant differences have been observed in the frequency of certain dental anomalies between genders. Supernumerary teeth are observed twice as frequently in males at a frequency of 2.6% compared to females, and this difference has been found to be statistically significant ($p = 0.014$). Additionally, ectopia and mesiodens anomalies have higher frequencies in females at rates of 7.8% and 2.8% respectively, and these differences are statistically significant (For ectopia $p = 0.035$, for mesiodens $p = 0.029$).

Table 3 presents the distribution of the number of dental anomalies according to gender. Looking at the conditions of individuals having dental anomalies, 39.3% of individuals with a single dental anomaly are male, and 56.7% are female. The rates of individuals with two or more dental anomalies are 1.8% in males and 2.2% in females. The obtained p-values indicate that there is no significant difference between genders in the number of dental anomalies ($p = 0.716$ for a single dental anomaly, $p = 0.818$ for two or more dental anomalies).

Discussion

Developmental anomalies are disorders that occur during the processes of tooth development and can range from simple isolated defects to symptoms of specific syndromes (10,11). These anomalies can complicate dental treatments such as root canal treatment or tooth extraction and can lead to malocclusion, increased sensitivity, and aesthetic problems (1,12). Teeth with anomalies are typically asymptomatic, and their identification by clinicians is often done through clinical or radiographic examination (7). Panoramic radiography is an initial radiographic examination method that provides a comprehensive view of the teeth, jaws, maxillary sinuses, nasal fossa, and temporomandibular joints (13). Therefore, in this study, dental anomalies were determined by evaluating orthopantomographic images. The frequency and types of dental anomalies vary within and between populations. Studies in the literature have reported that the prevalence of dental anomalies ranges between 1.73% and 74% (14-16). The prevalence of dental anomalies in the population studied in this research was found to be 13.78%. The variability in prevalence can be explained by the variability of geographical and genetic factors, as well as the use of different sampling and diagnostic methods (8,12,14). The age range of the examined population is also important both in terms of prevalence and distribution of anomalies (16). This study included individuals aged 5-16 years, and we consider that the type and prevalence of anomalies might be lower in this age group since the eruption time for some teeth has not yet arrived.

In this study, numerical anomalies were found to be the most frequently encountered type of anomaly, with hypodontia being the most common anomaly in this group with a prevalence of 46.9%. The prevalence of congenital tooth absence, excluding third molars, has been reported to range between 0.15% and 16.2% (17). This datas does not support the results of this study which may be due to the genetic characteristics of the examined population and the diagnostic methods used. A cross-sectional study conducted in the Turkish population reported a 1.8% rate of dental anomalies, with numerical anomalies being the most frequently observed anomaly (18). Another study in the Turkish population reported hypodontia (4.4%) as the most common dental anomaly (19). These studies show similarities. Furthermore, consistent with similar studies, no statistically significant difference was found in the prevalence of hypodontia between genders in study (20,21). Based on the findings of study, we believe that gender is not a determining factor in the frequency of hypodontia; it can vary depending on genetic factors and characteristics of the selected population, and understanding these factors can make significant contributions to clinical practices.

In this study, the diagnosis of taurodontism was made according to the taurodontism index developed by Shifman and Channel, and taurodontism was found to be the most common shape anomaly with a prevalence of 20.2%. In the literature, the prevalence of taurodontism has been reported to range between 0.02% and 60% (3,18), and study's data is consistent with the literature. Many studies evaluating taurodontism in early ages do not mention the method used for diagnosis (14,16,18,21,22), and it has been reported that the prevalence of taurodontism in individuals under 20 years of age is lower due to the difficulty in diagnosing taurodontism in permanent teeth with incomplete root development (3,22). We believe that when evaluating the diagnosis and prevalence of taurodontism, genetic differences, the age range of the population, and the diagnostic criteria used have a significant impact.

Ectopic eruption is a permanent tooth malposition affecting the primary tooth and leading to its early loss due to insufficient growth in the jaw or jaw segment (23). The prevalence of ectopic eruption has been reported to range between 0.01% and 8.9% in the literature (3,18). In our study, the prevalence of ectopia was determined to be 10.8%, and its frequency was found to be higher in females compared to males. A study evaluating the prevalence of ectopic eruption using different diagnostic methods showed that out of 47 patients with ectopic eruption, 23 were female, indicating no significant difference between genders (24). Barberia-Leache et al. (25) did not find a statistically significant difference between genders in ectopic eruption. In their study, Cheyne et al. (26) reported that one in every 50 children had a tooth with ectopic eruption, which was more common in the maxilla and among males. Differences among studies could be attributed to genetic factors, age range, and the size of the sample selected.

Supernumerary teeth, which occur in both deciduous and permanent dentition due to environmental and genetic factors, are extra teeth formed in addition to the normal number of teeth (27). Although it is thought that these teeth develop due to environmental or genetic factors, their etiology is not fully understood (28,29). In study, supernumerary teeth were found with a prevalence of 2.6% in males, twice as frequently as in females. A study found the prevalence of supernumerary teeth to be 0.98%, with a male-to-female ratio of 1.84:1 (30). Another study identified a prevalence of 1.6% for supernumerary teeth, with a higher rate in male patients (19). Yet another study reported that while there was no difference in the distribution of genders during deciduous dentition, supernumerary teeth were more common in males than in females during permanent dentition (31). This finding could be attributed to the non-homogeneity of our sample size and the influence of genetic factors. Mesiodens is the most common type of supernumerary tooth. In study, the prevalence of mesiodens was determined to be 6.8%, with statistically significant results found more frequently in males compared to females. The literature reports that the prevalence of supernumerary teeth does not differ by gender during the deciduous dentition period, but in the permanent dentition period, it is twice as common in males compared to females (31-33). A study investigating the frequency of mesiodens in the Turkish population found a statistically significant frequency of mesiodens in male patients with a ratio of 2.17:1 (34). The size of the study's sample, its demographic characteristics, and the criteria for selecting the sample can affect the generalizability of the results obtained.

Conclusion

Although the prevalence of dental anomalies varies among studies, we believe that the findings of this study will make significant contributions to the literature. Various factors such as genetic and ethnic factors, age range, the size of the selected sample, and the criteria used in diagnosis can cause differences between studies. Among the limitations of our study, selecting a broader sample and to support clinical evaluation with radiographic assessment in future studies could enhance the reliability of the results obtained.

Authorship Contributions: Concept: B.K.E., Y.P.; Design: B.K.E., Y.P.; Supervision: S.Y.; Materials: B.K.E., G.K.D.; Data: B.K.E., S.Y., G.K.D.; Analysis: Y.P., S.Y.; Literature search: B.K.E., Y.P.; Writing: B.K.E., Y.P., S.Y., G.K.D.; Critical revision: S.Y., G.K.D.

Use of AI for Writing Assistance: Not declared

Source of Funding: None declared.

Conflict of Interest: The authors did not report a conflict of interest.

Ethical Approval: Ethics committee approval for this study was obtained from Fırat University Non-Interventional Ethics Committee (2024/02-07) .

References

1. Saberi EA, Ebrahimipour S. Evaluation of developmental dental anomalies in digital panoramic radiographs in Southeast Iranian Population. J Int Soc Prev Community Dent 2016; 6: 291–5. [CrossRef]
2. White SC, Pharoah MJ. Oral Radiology: Principles and Interpretation. 6th ed. St Louis, MO: Mosby Elsevier; 2009.
3. Laganà G, Venza N, Borzabadi-Farahani A, et al. Dental anomalies: Prevalence and associations between them in a large sample of non-orthodontic subjects, a cross-sectional study. BMC Oral Health 2017; 17: 62. [CrossRef]
4. Jahanimoghadam F. Dental anomalies: An update. Adv Hum Biol 2016; 6: 112–8. [CrossRef]
5. Goswami M, Bhardwaj S, Grewal N. Prevalence of shape-related developmental dental anomalies in India: A retrospective study. Int J Clin Pediatr Dent 2020; 13: 407–11. [CrossRef]
6. Afify AR, Zawawi KH. The prevalence of dental anomalies in the Western region of saudi arabia. ISRN Dent 2012; 2012: 837270. [CrossRef]
7. Mukhopadhyay S, Mitra S. Anomalies in primary dentition: Their distribution and correlation with permanent dentition. J Nat Sci Biol Med 2014; 5: 139–43. [CrossRef]
8. Özveren N, Atay MT. Types and prevalence of dental anomaly in Turkish pediatric patients of Trakya region. [Article in Turkish] Turkiye Klinikleri J Dent Sci 2020; 26: 362–70. [CrossRef]
9. Kapdan A, Kustarci A, Buldur B, et al. Dental anomalies in the primary dentition of Turkish children. Eur J Dent 2012; 6: 178–83. [CrossRef]
10. Hall C, Hallett K, Manton D. The association between Cri du chat syndrome and dental anomalies. J Dent Child (Chic) 2014; 81: 171–7.
11. Marques LS, Alcântara CE, Pereira LJ, et al. Down syndrome: A risk factor for malocclusion severity? Braz Oral Res 2015; 29: 44. [CrossRef]
12. Shokri A, Poorolajal J, Khajeh S, et al. Prevalence of dental anomalies among 7- to 35-year-old people in Hamadan, Iran in 2012-2013 as observed using panoramic radiographs. Imaging Sci Dent 2014; 44: 7–13. [CrossRef]
13. White SC, Pharoah MJ. Oral Radiology: Principles and Interpretation. Amsterdam: Elsevier; 2012.
14. Patil S, Doni B, Kaswan S, et al. Prevalence of dental anomalies in Indian population. J Clin Exp Dent 2013; 5: e183–6. [CrossRef]
15. Aren G, Guven Y, Guney Tolgay C, et al. The prevalence of dental anomalies in a Turkish population. J Istanb Univ Fac Dent 2015; 49: 23–8. [CrossRef]
16. Celebi F, Taşkan M, Turkal M, et al. Dental anomaly prevalence in middle Black Sea population. [Article in Turkish] Cumhuriyet Dent J 2015; 18: 343–50.
17. Rakhshan V. Congenitally missing teeth (hypodontia): A review of the literature concerning the etiology, prevalence, risk factors, patterns and treatment. Dent Res J (Isfahan) 2015; 12: 1–13. [CrossRef]
18. Almaz ME, Sonmez IS, Oba AA. Prevalence and distribution of developmental dental anomalies in pediatric patients. Meandros Med Dental J 2017; 18: 130–3. [CrossRef]
19. Polat Y, Akleyin E. Evaluation of dental anomalies of pediatric patients during the COVID-19 pandemic process. Available at: https://www.turkiyeklinikleri.com/article/en-covid-19-pandemisi-surecinde-cocuk-hastalarin-dis-anomalilerinin-degerlendirilmesi-97785.html. Accessed Jul 19, 2024.
20. Yildiz S, Osman A, Tekin S, et al. Evaluation of the hypodontia prevalence among 8-15 years old children in Elaziğ province, from the eyes of parents: A qualitative research. [Article in Turkish] J Inonu Univ Health Serv Vocat Sch 2022; 10: 941–7. [CrossRef]
21. Ayrancı F. Evaluation of the prevalence of congenital teeth deficiencies in the middle Black Sea region children. [Article in Turkish] Suleyman Demirel Univ Inst Health Sci 2019; 10: 137–40.
22. Sumer A, Akça T, Köprülü H. Dental anomalies in children: Panoramic radiographic evaluation. [Article in Turkish] Ondokuz Mayıs Univ Fac Dent 2004; 5: 81–4.
23. Özdemir DS, Altan H. Ectopic eruption of permanent first molar teeth. [Article in Turkish] Yeditepe Üniv Diş Hekim Fak Derg 2021; 17: 68–74. [CrossRef]
24. Özdemir DS, Altan H. Use of two different classification

systems to determine the characteristics of ectopic eruption in the first permanent molars: A retrospective cross-sectional study. Turkiye Klinikleri J Dent Sci 2022; 28: 618–23. [CrossRef]
25. Barberia-Leache E, Suarez-Clúa MC, Saavedra-Ontiveros D. Ectopic eruption of the maxillary first permanent molar: Characteristics and occurrence in growing children. Angle Orthod 2005; 75: 610–5.
26. Cheyne VD, Wessels KE. Impaction of permanent first molar with resorption and space loss in region of deciduous second molar. J Am Dent Assoc 1947; 35: 774–87. [CrossRef]
27. Scarfe W, Farman A, White S, et al. Oral Radiology- Principles And Interpretation. Amsterdam: Elsevier; 2009.
28. Batra P, Duggal R, Parkash H. Non-syndromic multiple supernumerary teeth transmitted as an autosomal dominant trait. J Oral Pathol Med 2005; 34: 621–5. [CrossRef]
29. Erdem MA, Çankaya B, Güven G, et al. Supernumerary teeth. [Article in Turkish] J Istanbul Univ Fac Dent 2011; 45: 15–8.
30. Arikan V, Ozgul BM, Firdevs TO. Prevalence and characteristics of supernumerary teeth in a child population from Central Anatolia - Turkey. Oral Health Dent Manag 2013; 12: 269–72.
31. Rajab LD, Hamdan MA. Supernumerary teeth: Review of the literature and a survey of 152 cases. Int J Paediatr Dent 2002; 12: 244–54. [CrossRef]
32. Kim SG, Lee SH. Mesiodens: A clinical and radiographic study. J Dent Child (Chic) 2003; 70: 58–60.
33. Tyrologou S, Koch G, Kurol J. Location, complications and treatment of mesiodentes- A retrospective study in children. Swed Dent J 2005; 29: 1–9.
34. Ertaş ET, Sisman Y, Atıcı MY. The frequency, characteristics and complications of meziodens in Turkish population. Cumhuriyet Dent J 2013; 16: 267–72.

ORIGINAL ARTICLE

Turk Endod J 2024;9(2):77–83
doi: 10.14744/TEJ.2024.22931

The perspectives of dental clinical students about the challenges of endodontic procedures

Selin Göker Kamalı,[1] Yaren Tuana Altınova,[1] Betül Aycan Alim Uysal,[2] Dilek Türkaydin,[1] Hesna Sazak Öveçoğlu[1]

[1]*Department of Endodontics, Faculty of Dentistry, Marmara University, Istanbul, Türkiye*
[2]*Department of Endodontics, Faculty of Dentistry, Sağlık Bilimleri University, Istanbul, Türkiye*

Purpose: To evaluate the opinions of dental clinic students regarding the challenges of endodontic therapy and compare their responses based on their academic years.

Methods: A survey was prepared to evaluate the difficulties experienced by students regarding anesthesia, taking radiographs, use of rubber dam, cavity preparation, identifying radiographic apex, instrumentation, irrigation, intracanal medicament application, root canal filling, and temporary restoration procedures. The survey, consisting of 13 main questions (with yes/no answers) and 13 sub-questions (multiple choice), was responded to by 60 fourth-year and 60 fifth-year dentistry students. The Pearson Chi-Square and Fisher's Exact tests were applied to evaluate the students' answers according to their academic years.

Results: Taking radiographs, determining the master cone, and filling the root canal were the most challenging endodontic procedures. There was a statistically significant difference between the responses of fourth- and fifth-year students to the main questions regarding root canal filling and access cavity preparation ($p<0.05$).

Conclusion: During training, more emphasis should be placed on taking radiographs, identifying the master cone, and filling the root canals. Fifth-year students performing endodontic treatment of anatomically difficult cases were found to have less self-efficacy in filling root canals and preparing the endodontic access cavity.

Keywords: Dental education; dental students; endodontics; root canal treatment.

Introduction

Dental education should enable dental students to perform endodontic procedures independently, confidently, and successfully upon graduation (1,2). Many variables, such as clinical experience, practical application of theory, student efforts, student-patient and student-teacher relationships, have a significant impact on students' academic and professional development (3,4). Clinical experiences while applying endodontic therapies affect students' self-efficacy. As the number of root canal therapies they perform on patients increases, students' self-efficacy rises. However, it has been stated that treating challenging end-

Cite this article as: Göker Kamalı S, Altınova YT, Alim Uysal BA, Türkaydın D, Sazak Öveçoğlu H. The perspectives of dental clinical students about the challenges of endodontic procedures. Turk Endod J 2024;9:77-83.
Correspondence: Selin Göker Kamalı . Faculty of Dentistry, Marmara University, Istanbul, Türkiye
Tel: +90 216 – 777 50 00 e-mail: dtselingoker@gmail.com
Submitted: February 26, 2024 Revised: April 03, 2024 Accepted: April 04, 2024 Published: August 29, 2024

odontic cases could negatively impact students' self-efficacy (5). Many dental students reported feeling inadequate to perform endodontic procedures, especially on molars with complex root canals (6).

On the other hand, the self-confidence of dentistry students may significantly affect the success of endodontic treatment. By identifying the difficulties students encounter while performing root canal treatment and adopting approaches to overcome them, learning can be enhanced, and patients can be provided with better care. In this regard, students' feedback is very important for educational improvements (7). The perceptions of dentistry clinical students on root canal treatment procedures are a valuable resource in developing teaching strategies (8). Therefore, the purpose of this survey was to assess the perspectives of students who finished their Endodontics clinical training at Marmara University Faculty of Dentistry regarding the challenges of endodontic therapy.

Materials and Methods

This cross-sectional survey was conducted at Marmara University Faculty of Dentistry. In this school, endodontic education starts in the second year of dentistry school and lasts until graduation. Second-year dentistry students receive pre-clinical training that includes performing endodontic procedures on extracted teeth. Third-year students observe final-year students in the endodontics clinic and complete root canal treatment of a single-rooted tooth. While fourth-year students are expected to perform root canal therapy mostly on single-root teeth (at least 2 molar teeth), fifth-year students are required to treat mainly molars. Also, theoretical lessons continue from the second to the fourth year.

A survey was prepared to evaluate the difficulties experienced by students regarding anesthesia, application of radiographic techniques, use of rubber dam, cavity preparation, canal access, determination of working length, instrumentation, irrigation, intracanal medicament application, root canal filling, and temporary restoration procedures during endodontic treatment. The survey, consisting of 13 main questions (with yes/no answers) and 13 subquestions (with multiple choices), was created by modifying the survey in the study of Tavares et al. (9). A pilot test was conducted to eliminate the risk of bias and verify that the questions were understandable by the participants.

This study was approved by the Ethics Committee of Marmara University Faculty of Health Sciences (protocol no: 110-30.11.2023). The minimum total sample size was determined as 88 using the G. Power-3.1.9.2 program (α = 0.05; power = 0.80; effect size = 0.3) (10). Fourth and fifth-year students who completed their endodontics clinical internship at Marmara University Faculty of Dentistry in the first semester of the 2023-2024 academic year were included in the research. The survey was answered by 60 fourth and 60 fifth-year dental students.

Statistical Analyses

Statistical analyses were performed in the IBM SPSS Statistics 25 program. (SPSS Inc., Chicago, IL, USA) Descriptive statistics of the research data were expressed as numbers and percentages. The Pearson Chi-Square and Fisher's Exact tests were applied to evaluate the answers given by the students according to their academic years. The significance level was determined as 0.05.

Results

The distribution of students' answers to the survey questions according to academic years is given in Table 1. Taking radiographs, determining the master cone, and filling the root canals were the most challenging endodontic procedures. On the other hand, there was a statistically significant difference between the answers provided by fourth and fifth-year students to questions Q4, Q5sq, Q7sq, Q12, Q12sq, and Q13 ($p < 0.05$).

To the question "Did you encounter any difficulties during the preparation of the endodontic access cavity? (Q4)," the majority of the fourth-grade students (71.7%) answered "no," while the majority of the fifth-grade students (56.7%) answered "yes" ($p = 0.002$).

All of the participants who responded "premolar teeth" to the question "Which option was most challenging for you when you encountered difficulties during the removal of the pulp chamber roof? (Q5sq)" were fourth-year students, while almost all of the fifth-year students (94.1%) responded "molar teeth" ($p = 0.001$).

In response to the question "Which tooth group was the most difficult for you when determining the radiographic apex? (Q7sq)," all of the participants who answered "maxillary anterior," "mandibular anterior," "maxillary canine," "maxillary premolar," and "mandibular premolar" were fourth-grade students. The majority of fifth-grade students (61.5%) answered "maxillary molar" to this question ($p = 0.011$).

The participants who answered "no" to the question "Did you encounter any difficulties during root canal filling? (Q12)" were mostly fourth-year students (65%), and those who answered "yes" were mostly fifth-year students (57.5%) ($p = 0.020$). All of the respondents who answered "accessory cone selection" to the question "Which option was the most challenging for you during root canal filling (Q12sq)" were fourth-year students; all of the respon-

Table 1. Distribution of students' answers to the questions

Question		Answers	Fourth-year (n = 60)			Fifth-year (n = 60)			Total (n = 120)		
			n	%	%Y.	n	%	%Y.	n	%	p
Q1	Did you encounter any difficulties during anesthesia?	No	35	48.6	58.3	37	51.4	61.7	72	60	0.709*
		Yes	25	52.1	41.7	23	47.9	38.3	48	40	
Q1sq	If your answer is yes, which option was the most challenging for you?	Inferior alveolar nerve block	22	52.4	88.0	20	47.6	90.9	42	89.4	1.000†
		Mental nerve block	2	66.7	8.0	1	33.3	4.5	3	6.4	
		Posterior superior alveolar nerve block	1	50.0	4.0	1	50.0	4.5	2	4.3	
		Infiltration	0	0	0	0	0	0	0	0.0	
Q2	Did you encounter any difficulties during the rubber dam application?	No	25	55.6	41.7	20	44.4	33.3	45	37.5	0.346*
		Yes	35	46.7	58.3	40	53.3	66.7	75	62.5	
Q2sq	If your answer is yes, which option was the most challenging for you?	Clamp choice	5	55.6	14.3	4	44.4	10.0	9	12.0	0.081†
		Clamp adaptation	20	37.7	57.1	33	62.3	82.5	53	70.7	
		Adaptation of rubber dam	6	75.0	17.1	2	25.0	5.0	8	10.7	
		Other	4	80.0	11.4	1	20.0	2.5	5	6.7	
Q3	Did you encounter any difficulties in taking radiographs?	No	19	51.4	31.7	18	48.6	30.0	37	30.8	0.843*
		Yes	41	49.4	68.3	42	50.6	70.0	83	69.2	
Q3sq	If your answer is yes, which option was the most challenging for you?	Positioning of the patient	0	0.0	0.0	2	100.0	4.8	2	2.4	0.663†
		Placement of periapical film in the mouth	2	40.0	4.9	3	60.0	7.1	5	6.0	
		Positioning the periapical X-ray cone	13	48.1	31.7	14	51.9	33.3	27	32.5	
		Patient-related factors (Gag reflex, the patient's inability to hold the film, etc.)	26	53.1	63.4	23	46.9	54.8	49	59.0	
Q4	Did you encounter any difficulties during the preparation of the endodontic access cavity?	No	43	62.3	71.7	26	37.7	43.3	69	57.5	0.002*
		Yes	17	33.3	28.3	34	66.7	56.7	51	42.5	
Q4sq	If your answer is yes, which option was the most challenging for you?	Direct access to canals	12	30.8	70.6	27	69.2	79.4	39	76.5	0.257†
		Contour shape	0	0.0	0.0	1	100.0	2.9	1	2.0	
		Convenience form	3	42.9	17.6	4	57.1	11.8	7	13.7	
		Cleaning the cavity	0	0.0	0.0	2	100.0	5.9	2	3.9	
		Removal of carious dentin and defective restoration	2	100.0	11.8	0	0.0	0.0	2	3.9	
Q5	Did you encounter any difficulties during the removal of the pulp chamber roof?	No	35	57.4	58.3	26	42.6	43.3	61	50.8	0.100*
		Yes	25	42.4	41.7	34	57.6	56.7	59	49.2	
Q5sq	If your answer is yes, which option was the most challenging for you?	Anterior teeth	0	0.0	0.0	2	100.0	5.9	2	3.4	0.001†
		Premolar teeth	7	100.0	28.0	0	0.0	0.0	7	11.9	
		Molar teeth	18	36.0	72.0	32	64.0	94.1	50	84.7	
Q6	Did you have difficulty distinguishing root canals on radiography?	No	20	43.5	33.3	26	56.5	43.3	46	38.3	0.260*
		Yes	40	54.1	66.7	34	45.9	56.7	74	61.7	
Q6sq	If your answer is yes, which option was the most challenging for you?	Maxillary incisors	0	0.0	0.0	0	0.0	0.0	0	0.0	0.185†
		Mandibular incisors	0	0.0	0.0	0	0.0	0.0	0	0.0	
		Maxillary canine	1	100.0	2.5	0	0.0	0.0	1	1.4	
		Mandibular canine	0	0.0	0.0	0	0.0	0.0	0	0.0	
		Maxillary premolars	6	60.0	15.0	4	40.0	11.8	10	13.5	
		Mandibular premolars	1	100.0	2.5	0	0.0	0.0	1	1.4	
		Maxillary molars	15	41.7	37.5	21	58.3	61.8	36	48.6	
		Mandibular molars	17	65.4	42.5	9	34.6	26.5	26	35.1	
Q7	Did you have difficulty determining the radiographic apex of teeth?	No	40	54.1	66.7	34	45.9	56.7	74	61.7	0.260*
		Yes	20	43.5	33.3	26	56.5	43.3	46	38.3	
Q7sq	If your answer is yes, which option was the most challenging for you?	Maxillary incisors	1	100.0	5.0	0	0.0	0.0	1	2.2	0.011†
		Mandibular incisors	1	100.0	5.0	0	0.0	0.0	1	2.2	
		Maxillary canine	1	100.0	5.0	0	0.0	0.0	1	2.2	
		Mandibular canine	0	0.0	0.0	0	0.0	0.0	0	0.0	
		Maxillary premolars	6	85.7	30.0	1	14.3	3.8	7	15.2	

		Mandibular premolars	1	100.0	5.0	0	0.0	0.0	1	2.2	
		Maxillary molars	7	30.4	35.0	16	69.6	61.5	23	50.0	
		Mandibular molars	3	25.0	15.0	9	75.0	34.6	12	26.1	
Q8	Did you encounter any difficulties during mechanical instrumentation of root canals?	No	24	48.0	40.0	26	52.0	43.3	50	41.7	0.711*
		Yes	36	51.4	60.0	34	48.6	56.7	70	58.3	
Q8sq	If your answer is yes, which option was the most challenging for you?	Determination of the initial apical file (IAF)	5	71.4	13.9	2	28.6	5.9	7	10.0	0.146†
		Removal of vital or necrotic tissues	6	66.7	16.7	3	33.3	8.8	9	12.9	
		Apical shaping	15	41.7	41.7	21	58.3	61.8	36	51.4	
		Determination of the master apical file (MAF)	7	77.8	19.4	2	22.2	5.9	9	12.9	
		Step-back technique	3	33.3	8.3	6	66.7	17.6	9	12.9	
Q9	Did you encounter any difficulties during irrigation of root canals?	No	50	51.5	83.3	47	48.5	78.3	97	80.8	0.487*
		Yes	10	43.5	16.7	13	56.5	21.7	23	19.2	
Q9sq	If your answer is yes, which option was the most challenging for you?	Positioning the irrigation needle 1-2 mm shorter than the working length	2	33.3	20.0	4	66.7	30.8	6	26.1	0.660†
		Up-and-down movemen t of the irrigation needle	8	47.1	80.0	9	52.9	69.2	17	73.9	
Q10	Did you encounter any difficulties during intracanal medicament application?	No	52	49.5	86.7	53	50.5	88.3	105	87.5	0.783*
		Yes	8	53.3	13.3	7	46.7	11.7	15	12.5	
Q10sq	If your answer is yes, which option was the most challenging for you?	Preparation	2	100.0	25.0	0	0.0	0.0	2	13.3	0.467†
		Application	6	46.2	75.0	7	53.8	100.0	13	86.7	
Q11	Did you encounter any difficulties during the determination of the master cone?	No	16	42.1	26.7	22	57.9	36.7	38	31.7	0.239*
		Yes	44	53.7	73.3	38	46.3	63.3	82	68.3	
Q11sq	If your answer is yes, which option was the most challenging for you?	Master cone selection	2	50.0	4.5	2	50.0	5.3	4	4.9	0.372†
		Radiographic verification of master point	8	40.0	18.2	12	60.0	31.6	20	24.4	
		Tactile test (tug-back)	34	58.6	77.3	24	41.4	63.2	58	70.7	
Q12	Did you encounter any difficulties during root canal filling?	No	26	65.0	43.3	14	35.0	23.3	40	33.3	0.020*
		Yes	34	42.5	56.7	46	57.5	76.7	80	66.7	
Q12	If your answer is yes, which option was sqthe most challenging for you?	Sealer manipulation	0	0.0	0.0	2	100.0	4.3	2	2.5	0.036†
		Accessory cone selection	4	100.0	11.8	0	0.0	0.0	4	5.0	
		Placement of gutta percha	4	25.0	11.8	12	75.0	26.1	16	20.0	
		Lateral condensation	19	46.3	55.9	22	53.7	47.8	41	51.3	
		Removal of excess gutta-percha	0	0.0	0.0	3	100.0	6.5	3	3.8	
		Cleaning the cavity after filling	7	50.0	20.6	7	50.0	15.2	14	17.5	
Q13	Did you encounter any difficulties during the temporary restoration application?	No	42	43.3	70.0	55	56.7	91.7	97	80.8	0.003*
		Yes	18	78.3	30.0	5	21.7	8.3	23	19.2	
Q13sq sq	If your answer is yes, which option was the most challenging for you?	Material selection	2	100.0	11.1	0	0.0	0.0	2	8.7	0.726†
		Implementation	13	81.3	72.2	3	18.8	60.0	16	69.6	
		Other	3	60.0	16.7	2	40.0	40.0	5	21.7	

%: Percentage of rows; %Y: Column percentage for academic year; *Pearson Chi-Square; †Fisher's Exact Test. The significance level was determined to be less than 0.05.

dents who answered "sealer manipulation" and "removal of excess gutta percha" and the majority of the respondents (75%) who answered "placement of the gutta percha" were fifth-year students ($p = 0.036$).

The majority of students who responded "no" to the question "Did you encounter any difficulties during the temporary restoration application (Q13)" were in fifth grade (56.7%), whereas the majority of those who responded "yes" were in fourth grade (78.3%) ($p = 0.003$).

There was no statistically significant difference between the answers given by fourth and fifth-year students to other questions. It was determined that the answers to those questions did not change according to the academic year ($p > 0.05$).

Discussion

The majority of students think that endodontics is a challenging and demanding field due to the variety of root canal anatomy and the necessity of treating patients appropriately (4). Dental students' perception of difficulty regarding endodontic procedures significantly affects their self-confidence, motivation, and overall performance during treatment (11). However, undergraduate dentistry students should have gained the ability to perform uncomplicated endodontic treatments at the end of their education (1). Therefore, it is crucial to identify the areas where students have difficulties and find solutions to overcome them.

Sixty percent of the students stated that they did not experience any problems during anesthesia administration. Almutairi et al. (11) reported this rate of around 70%, while Kaplan et al. (12) observed this rate of approximately 80%. Ninety-point-nine percent of our participants who had problems with anesthesia said inferior alveolar nerve block was challenging. Previous research has shown that students who practice on local anesthesia models are more prepared, more confident, and have improved motor control when administering anesthesia to patients in the clinic (13). Using these models as pre-clinical training tools can help our students to have a smoother anesthesia experience for inferior alveolar nerve block. The pulpal status of the tooth may also contribute to students' problems with inferior alveolar nerve block anesthesia. Clinical studies have shown that the failure rate of inferior alveolar nerve block in patients diagnosed with irreversible pulpitis is 43-83% (14).

The current study revealed that 62.5% of students had problems with rubber dam application, mostly during clamp adaptation. On the contrary, previous studies have reported that approximately 66-92% of students did not perceive this stage as difficult (9,11,12). The reason for this contrast may be that our students applied the rubber dam directly on the patient for the first time in the third grade. Almutairi et al. (11) stated that students received practical training on rubber dam in their second and third years. As a result of these evaluations, it was decided to include comprehensive hands-on training on rubber dams in the pre-clinical program so that students can have a better experience with rubber dams in the clinic.

During root canal treatment, working length is determined using radiographic methods or electronic apex locators (15). In our school, periapical radiography is used for this step. When determining the working length, students need to take a radiograph with optimum characteristics, distinguish the root canals, and determine the radiographic apex. Considering the results of all survey questions, students had the most difficulty in taking radiography (almost 70%). Patient-related factors such as the gag reflex and the patient's inability to hold the film were the most challenging factors for them. In such circumstances, using a film holder for periapical radiography may be beneficial. However, a previous investigation indicated that incorrect angulation relative to anatomical locations was one of the most common faults at this step (16). On the other hand, 61.7% of students had difficulties distinguishing the root canals, whereas the same percentage of students said they had no trouble identifying the radiographic apex of teeth. In both stages, the most challenging tooth group for the students was the maxillary molars. In cases where it is difficult to take radiographs, distinguish the root canals, or identify the radiographic apex, using apex locators to determine working length can help students feel more comfortable in the endodontic clinic.

The majority of fourth-year students had no trouble preparing the endodontic access cavity, whereas the majority of fifth-year students struggled. This may be because fifth-year students often perform root canal treatment on anatomically challenging molars (17). Fourth-year students answer the questions based on their practical experience with simple endodontic treatments. Furthermore, the majority claimed that gaining direct access to the canals was the most difficult step in endodontic cavity preparation. Regarding the removal of the pulp chamber roof, more than half of the students stated that they did not experience any difficulties, similar to previous studies (11,12). Although most students, regardless of grade level, stated that removing the pulp chamber roof on molars was more difficult, seven fourth-grade students stated that they experienced the most difficulty in premolars.

For successful endodontic treatment, root canals must be properly shaped, irrigated, and subsequently filled (18). It is critical to preserve the original canal form and avoid procedural errors such as ledges and zips during root canal shaping (19). Almost 60% of the students had trouble with canal mechanical instrumentation, particularly with apical shaping, whereas previous studies reported this rate as 31-36% (11,12). The reason for this discrepancy could be that prior research did not include sub-questions with multiple choices, so their participants were unable to correlate the difficulties they encountered with the question. Allowing students to use rotary instruments in curved or narrow canals may reduce the perception of difficulty associated with the mechanical instrumentation of root canals (20). However, it has been reported that manual hand instruments are safer than rotary instruments in terms of instrument fracture in endodontic treatments performed by students (21). For this reason, it is emphasized that students should receive intensive theoretical and pre-clinical training before using rotary file systems in the clinic (21).

A previous study reported that one of the most difficult situations for students was their inability to manage the length of the main cone (22). Similarly, about 70% of our participants had trouble determining the master cone. Many students responded that their difficulty was a sense of tug-back. This could be related to the difficulty they had with apical shaping during mechanical instrumentation.

In contrast to earlier studies (11,12), it was observed that most students described the canal filling process, especially the lateral condensation process, as difficult. This discrepancy may be attributed to differences in dental schools' curriculum types and teaching strategies. The majority of the students who had problems with the canal filling were fifth-year students. Since they perform endodontic treatment in more difficult cases, they may be less confident in this regard (5). Approximately 80% of the students reported that they had no problems with irrigation, intracanal medicament, and temporary material applications. As expected, fourth-year students were the most likely to struggle with applying temporary materials.

Considering all the main questions, there was no endodontic procedure that the students had no problems with. At some stages, it was observed that a small number of students encountered difficulties. The general education program can be reorganized to address the issues that the majority have problems with. However, the problems experienced by the minority also need to be solved. Since pre-clinical and clinical education in dentistry provides lecturers with the opportunity to deal with students one-on-one, personalized approaches can be applied after learning the needs of each student through similar surveys and practical tests.

Conclusion

This study findings suggest that greater emphasis should be placed on taking radiographs, identifying the master cone, and filling root canals during the educational process. Fifth-year students performing endodontic treatment of anatomically difficult cases were found to have less self-efficacy in filling root canals and preparing the endodontic access cavity.

Authorship Contributions: Concept: SGK; Design: SGK, YTA, BAU; Supervision: DT, HSÖ; Materials: DT, HSÖ; Data: SGK, YTA; Analysis: SGK, BAU, DT, HSÖ; Literature search: SGK, YTA, BAU; Writing: SGK; Critical revision: SGK, BAU, DT, HSÖ.

Use of AI for Writing Assistance: Not declared

Source of Funding: None declared.

Conflict of Interest: None declared.

Ethical Approval: The study protocol was approved by the Marmara University Health Sciences Ethics Commitee (date: 30.11.2023, protocol no: 110).

References

1. Cowpe J, Plasschaert A, Harzer W, et al. Profile and competences for the graduating European dentist - Update 2009. Eur J Dent Educ 2010; 14: 193–202. [CrossRef]
2. De Moor R, Hülsmann M, Kirkevang LL, et al. Undergraduate curriculum guidelines for endodontology. Int Endod J 2013; 46: 1105–14. [CrossRef]
3. Lanning SK, Wetzel AP, Baines MB, et al. Evaluation of a revised curriculum: A four-year qualitative study of student perceptions. J Dent Educ 2012; 76: 1323–33. [CrossRef]
4. Rolland S, Hobson R, Hanwell S. Clinical competency exercises: Some student perceptions. Eur J Dent Educ 2007; 11: 184–91. [CrossRef]
5. Baaij A, Özok AR, Væth M, et al. Self-efficacy of undergraduate dental students in endodontics within Aarhus and Amsterdam. Int Endod J 2020; 53: 276–84. [CrossRef]
6. Murray CM, Chandler NP. Undergraduate endodontic teaching in New Zealand: Students' experience, perceptions and self-confidence levels. Aust Endod J 2014; 40: 116–22. [CrossRef]
7. Henzi D, Davis E, Jasinevicius R, et al. Appraisal of the dental school learning environment: The students' view. J Dent Educ 2005; 69: 1137–47. [CrossRef]
8. Oliver R, Kersten H, Vinkka-Puhakka H, et al. Curriculum structure: Principles and strategy. Eur J Dent Educ 2008; 12: 74–84. [CrossRef]
9. Tavares LG, Lima SMF, Lima MG, et al. Undergraduate dentistry students' perception of difficulties regarding endodontic treatment. Aust Endod J 2019; 45: 98–105. [CrossRef]
10. Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed. Hillsdale, New Jersey: Lawrence Erlbaum Associates; 1988.
11. Almutairi M, Alattas MH, Alamoudi A, et al. Challenges assessment in endodontics among undergraduate students. Cureus 2023; 15: e43215. [CrossRef]
12. Kaplan T, Sezgin GP, Sönmez-Kaplan S. Dental students' perception of difficulties concerning root canal therapy: A survey study. Saudi Endod J 2020; 10: 33–8. [CrossRef]
13. Brand HS, Baart JA, Maas NE, et al. Effect of a training model in local anesthesia teaching. J Dent Educ 2010; 74: 876–9. [CrossRef]
14. Göker Kamalı S, Türkaydın D. Acil endodontik tedavilerde anestezi. In: Ersev H, editor. Endodontide Acil

Durumların Yönetimi. 1st ed. Ankara: Türkiye Klinikleri; 2022. p. 7–11.
15. Sharma MC, Arora V. Determination of working length of root canal. Med J Armed Forces India 2010; 66: 231–4. [CrossRef]
16. Peker I, Alkurt MT. Evaluation of radiographic errors made by undergraduate dental students in periapical radiography. N Y State Dent J 2009; 75: 45–8.
17. Javed MQ, Bhatti UA. Students' performance in clinics and self-perceived Confidence in performing Endodontic procedures: A correlation study. Pak J Med Sci 2023; 39: 203–8. [CrossRef]
18. European Society of Endodontology. Quality guidelines for endodontic treatment: Consensus report of the European Society of Endodontology. Int Endod J 2006; 39: 921–30. [CrossRef]
19. Hülsmann M, Peters OA, Dummer PM. Mechanical preparation of root canals: Shaping goals, techniques and means. Endod Topics 2005; 10: 30–76. [CrossRef]
20. Kwak SW, Cheung GS, Ha JH, et al. Preference of undergraduate students after first experience on nickel-titanium endodontic instruments. Restor Dent Endod 2016; 41: 176–81. [CrossRef]
21. Alrahabi M. Comparative study of root-canal shaping with stainless steel and rotary NiTi files performed by preclinical dental students. Technol Health Care 2015; 23: 257–65. [CrossRef]
22. Mirza MB. Difficulties encountered during transition from preclinical to clinical endodontics among Salman bin Abdul Aziz University dental students. J Int Oral Health 2015; 7: 22–7.

ORIGINAL ARTICLE

Turk Endod J 2024;9(2):84–89
doi: 10.14744/TEJ.2024.00710

Can activation of root canal sealer enhance the penetration into lateral canals?

Öznur Sarıyılmaz, Evren Sarıyılmaz, Saadet Elpe

Department of Endodontics, Faculty of Dentistry, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye

Purpose: This study aimed to compare the efficacy of a resin-based canal sealer and a bioceramic canal sealer in obturating lateral canals, with and without the use of activation methods.

Methods: Lateral canals were created at apical positions of 3, 5, and 8 mm in eighty 3D-printed maxillary central teeth. After root canal preparation, the teeth were embedded in 1.5% agar agar to simulate periodontal tissues. The teeth were divided into two main groups based on the type of root canal sealer and further categorized into four subgroups for activation methods: Conventional, EDDY, EndoActivator, and Passive Ultrasonic. Root canals were filled using the single cone technique, and images were captured at 17× magnification. Sealer penetration into lateral canals was measured using ImageJ software. Activation methods were compared using the Kruskal-Wallis test; root levels were compared using the Friedman test, and comparisons between sealers were made with the Mann-Whitney U test at a 95% confidence level.

Results: Activation methods had no significant impact on sealer penetration for both types of sealers. In ultrasonic activation groups, the bioceramic sealer exhibited significantly higher penetration than the resin-based sealer at all root levels. In sonic activation groups, the bioceramic sealer showed significantly superior penetration, especially at the middle root level.

Conclusion: Activation methods did not significantly alter sealer penetration into lateral canals. Bioceramic-based root canal sealer demonstrated enhanced penetration compared to resin-based sealer, especially with ultrasonic and sonic activation.

Keywords: Bioceramic root canal sealer; EDDY; EndoActivator; passive ultrasonic activation.

Introduction

The long-term success of endodontic procedures relies on effectively sealing all openings of the root canal system to prevent bacterial infiltration (1,2). However, anatomical variations such as ramifications and lateral canals can pose challenges in achieving the goals (3,4). Lateral canals are formed due to interruption of Hertwig epithelial root sheath, such as a blood vessel emerged from the dental sac to dental papilla during the development of the dental root (5). The prevalence of lateral canals varies widely, ranging from 27.4 to 99% (3,6,7). Bacteria can potentially harbor in lateral canals, and these lateral canals also serve as a pathway to periodontal tissues for both bacteria and their byproducts, which can incite infection (4,8). Consequently, lateral canals may contribute to the failure of

Cite this article as: Sarıyılmaz Ö, Sarıyılmaz E, Elpe S. Can activation of root canal sealer enhance the penetration into lateral canals? Turk Endod J 2024;9:84-89.
Correspondence: Evren Sarıyılmaz. Faculty of Dentistry, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye
Tel: +90 286 – 263 35 33 e-mail: evrensariyilmaz@yahoo.com
Submitted: April 17, 2024 Revised: June 07, 2024 Accepted: June 26, 2024 Published: August 29, 2024

endodontic treatment (9-11). Filling the ramifications and lateral canals with sealers can enhance the success of endodontic treatment.

The flowability of the root canal sealer plays a crucial role in filling irregularities and voids within the root canal system, ultimately contributing to the achievement of a hermetic root canal filling (12). The acoustic energy generated by sonic and ultrasonic activation reduces the viscosity of the root canal sealer, increases its fluidity, and enhances its penetration into the canal walls and voids (13,14). Arslan et al. (15) demonstrated that the application of sonic and ultrasonic activation to epoxy-amine resin-based sealer increases their effectiveness in penetrating lateral canals.

There are studies available that evaluate the penetration of different root canal sealers into lateral canals (16-19). However, there is no study in the literature that examines the penetration of bioceramic-based root canal sealers into lateral canals following the application of activation. The aim of this study was to compare the effectiveness of various activation methods applied to two distinct root canal sealers concerning their penetration into the lateral canals. The null hypothesis posited that there would be no differences among the activation techniques.

Materials and Methods

Based on the findings of Wiesse et al. (13) and utilizing one-way ANOVA analysis, G*Power software (version 3.1, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) with $\alpha = 0.05$, power $(1\text{-}\beta) = 0.95$, effect size = 0.7308 and a mean standard deviation of 0.48, the required sample size for each group was determined to be 10. A total of eighty resin-based 3D printed maxillary central teeth, which have anatomic structure derived from real tomographic images of natural teeth, were utilized to assess the flow of filling materials.

The access cavity was created using a high-speed handpiece equipped with #4 carbide round burs. The working length was determined by using ISO #15 K-files, with 1 mm subtracted from the measured length at the point where the file first emerged from the apex. Root canals were instrumented up to Protaper X4 (Dentsply, Maillefer, Ballaigues, Switzerland).

During each file change, the canals were irrigated using 2 ml of 2.5% NaOCl (Cerkamed, Stalowa Wola, Poland) solution. Lateral canals were created on the mesial and distal surface at apical 3 mm, 5 mm, and 8 mm using a #15 engine-driven reamer.

The 3D-printed teeth were placed in 2 ml Eppendorf tube filled with 1.5% agar agar to simulate periodontal tissues. The teeth were randomly divided into two groups, one for resin-based root canal sealer (AH plus, Dentsply Maillefer, Germany) and the other for bioceramic-based root canal sealer (Bioserra, Dentac, Türkiye). Each group was further subdivided into four subgroups for different activation methods.

Before canal filling, the canals were irrigated once more with a NaOCl solution, and ultrasonic activation was performed for two cycles of 20 seconds each. After irrigation, the canals were dried with paper points. ProTaper X4 gutta-percha cones, positioned 2 mm shorter than the working length, were used to transfer the root canal sealer into the root canal. Sealer activations were then applied for each sealer group as described below.

Conventional Activation: A ProTaper X4 gutta-percha cone was positioned 2 mm shorter than the working length. Activation was performed using back-and-forth movements, repeated 10 times to ensure the penetration of the sealer into the lateral canals.

EDDY Activation: An EDDY polyamide tip (size 25/06, VDW, Munich, Germany) was mounted to the TA-200 (Micron, Tokyo, Japan) device and operated at 6000 Hz. The tip was inserted into the root canal, positioned 2 mm shorter than the working length, and activation was applied for 20 seconds, repeated twice.

EndoActivator Activation: An EndoActivator tip size (35/04, Dentsply, Maillefer, Ballaigues) was mounted to the EndoActivator device, and activation was applied for 20 seconds, positioned 2 mm shorter than the working length, repeated twice.

Passive Ultrasonic Activation: A size 25# ultrasonic tip (Woodpecker, Japan) was mounted to the VDW Ultra (VDW, Germany) device, and activation was applied for 20 seconds, positioned 2 mm shorter than the working length, and repeated twice.

After placing and activating the sealer, a ProTaper X4 gutta-percha cone was inserted into the root canal up to working length. Any excess of the gutta-percha cone was removed using a heated instrument, and the access cavities were sealed with temporary filling material.

Images of the teeth were captured using a dental operating microscope (OMG 2350, Zumax, Suzhou, China) at 17x magnification. Photographic images displaying the lateral canal fillings in each specimen were imported into Image Tool software (ImageJ software, version: 2.0.0-rc-43/1.51e, National Institutes of Health, Bethesda, USA). By using the measure tool of ImageJ software, the depth of sealer penetration into each lateral canal was measured and documented as the lateral canal filling percentage by an experienced endodontist (ES) who assessed the sealer penetration into the simulated lateral canals.

Statistical Analysis

Given that the data did not exhibit a normal distribution, as confirmed by the Shapiro-Wilk test, comparisons among activation methods were carried out using the Kruskal-Wallis test, while comparisons between root levels were conducted using the Friedman test. For comparisons between root canal sealers, the Mann-Whitney U test was employed, with a confidence level of 95% (p=0.05). All statistical analyses were performed using IBM SPSS Statistics 20 software (IBM SPSS Inc., Chicago, IL, USA).

Results

A total of 480 lateral canals from 80 teeth were assessed to evaluate root fillings. The primary root canals of all specimens were adequately filled. Therefore, this analysis focused solely on the fillings within the simulated lateral canals. The percentages of root canal sealer penetration into lateral canals at various levels are presented in Tables 1 and 2. In both groups of root canal sealers, activation of the root canal sealer did not yield a significant difference in terms of its penetration into the lateral canals. The localization of lateral canals did not significantly affect obturation ability, except in the passive activation group of the bioceramic canal sealer. The penetration of bioceramic root canal sealers was notably superior to that of resin-based root canal sealers. Particularly in the ultrasonic activation groups, the bioceramic root canal sealer exhibited statistically significantly higher penetration compared to the resin-based root canal sealer at all root canal levels (the p-values were 0.034, 0.000, and 0.027 for the coronal, middle, and apical levels, respectively). In the sonic activation groups, the bioceramic root canal sealer demonstrated significantly greater penetration compared to the resin-based root canal sealer at the middle root levels (p=0.013).

Discussion

During endodontic treatment, anatomical variations such as lateral canals can significantly impact the disinfection, filling, and overall success of root canal procedures (9-11). The effectiveness of lateral canal filling is influenced by the selection of root canal filling techniques and the type of root canal sealer, in addition to their specific characteristics (17-22). In the literature, numerous studies have been conducted to investigate the quality of lateral canal filling in teeth using various root canal filling techniques and sealers (12,15-23). In these studies, researchers either utilized pre-existing lateral canals present in extracted teeth (18) or artificially created lateral canals in these

Table 1. The mean, standard deviation, and quartile values of lateral canal fillings for epoxy-resin based root canal sealer.

	Coronal	Middle	Apical	p
Conventional	81.59 (13.51)	82.74 (18.37)	82.03 (22.36)	
	84.80 (77.42 – 92.45)	84.60 (79.25 – 92.4)	89.00 (77.30 – 96.77)	0.354
EDDY	65.73 (28.44)	79.92 (17.22)	72.20 (29.94)	
	74.90 (42.25 – 86.87)	86.20 (70.50 – 91.62)	82.55 (48.07 – 97.45)	0.186
EndoActivator	78.53 (17.72)	70.82 (25.76)	73.05 (20.85)	
	86.80 (69.95 – 89.97)	80.70 (54.20 – 88.8)	80.10 (61.87 – 85.87)	0.287
Passive Ultrasonic	71.70 (22.98)	78.56 (17.63)	70.42 (23.47)	
	78.70 (61.82 – 87.65)	76.30 (90.02)	77.60 (68.80 – 84.02)	0.819
p	0.241	0.259	0.054	

Table 2. The mean, standard deviation, and quartile values of lateral canal fillings for bioceramic root canal sealer.

	Coronal	Middle	Apical	p
Conventional	66.17 (34.86)	87.43 (11.21)	89.44 (7.97)	
	84.29 (26.73–93.08)	89.63 (82.45–96.23)	90.52 (83.77–95.03)	0.029
EDDY	70.16 (29.33)	89.01 (12.03)	81.41 (20.72)	
	80.62 (51.06–90.67)	92.66 (80.20–99.86)	87.41 (74.58–96.42)	0.262
EndoActivator	84.76 (18.54)	88.12 (9.23)	81.83 (20.98)	
	89.96 (81.26–95.61)	89.94 (83.81–95.35)	89.53 (78.25–95.10)	0.951
Passive Ultrasonic	79.42 (27.67)	90.14 (15.09)	77.26 (30.65)	
	91.42 (73.30–97.39)	94.31 (88.61–97.49)	94.06 (52.21–98.95)	0.157
P	0.219	0.476	0.760	

teeth (15,16,19,21). Additionally, transparent resin blocks (22,24) and plastic teeth (20,23) have been employed in experimental investigations. In this study, resin-based 3D printed teeth, which have anatomic structure derived from real tomographic images of natural teeth, were used due to the challenges associated with achieving standardization in terms of natural teeth's root dentin thickness and the lengths of the lateral canals. Lateral canals were created on resin teeth via a #15 engine-driven reamer because current 3D printing technology faces challenges in forming adequate narrow canals below 0.3 mm in diameter. However, a previous study revealed that only a tiny percentage of teeth have lateral canals wider than a #15 reamer, and in fact, over fifty percent of them have a smaller diameter than #10 reamer (25). In this study, we used a #15 reamer due to its similarity in dimensions to natural lateral canals and its stability and durability during the drilling of lateral canals in specimens.

Upon examining the previous studies, it becomes evident that various methods have been employed to create lateral canals. Fernández et al. (17) prepared artificial lateral canals using a 10-engine reamer at distances of 3, 6, and 10 mm from the apex. In the creation of artificial lateral canals, Arslan et al. (15) used an 8 K-file at distances of 2, 4, and 6 mm from the apex, while Candeiro et al. (12) utilized 6 and 10 K-file. In a separate study that employed decalcification techniques, artificial lateral canals were established at distances of 3, 6, and 10 mm from the root apex by introducing a #10 K-file perpendicular to the external surface (21,26). Almeida et al. (16) employed a 0.1 mm drill to create artificial lateral canals in teeth, positioning them at distances of 3 mm and 6 mm from the root apex. Karabucak et al. (23) created lateral canals on the mesial surface at apical positions of 2 mm, 6 mm, and 10 mm, as well as on the distal surface at apical positions of 4 mm, 8 mm, and 12 mm, using a Quantac file (15/0.2) in plastic teeth. In another study that utilized plastic teeth, prefabricated lateral canals with a width of 0.2 mm were established at distances of 2 mm, 5 mm, and 7 mm from the apex within the teeth (20). The dimensions of lateral canals in natural teeth have been defined in prior studies (6,16,27). Considering the dimensions mentioned in previous studies, artificial lateral canals were formed using a 15 K engine reamer, resulting in lateral canals with an approximate width of 150 µm. These lateral canals were established at distances of 2 mm, 5 mm, and 8 mm from the root apex.

ImageJ is a powerful image processing and analysis software developed in Java. It is highly regarded in scientific research due to its unique capabilities. It can operate on any available operating system. Additionally, it is open-source and free to use. ImageJ can display, edit, analyze, process, save, and print 8-bit to 32-bit images in various formats, including TIFF, JPEG, BMP, GIF, DICOM, FITS, and raw files. The software supports a range of standard image processing functions, including contrast manipulation, sharpening, smoothing, edge detection, and median filtering. It can also compute area and pixel value statistics for user-defined selections, measure distances and angles, and generate density histograms and line profile plots (28). In this study, the software's measure tool, which was run by using the pixel value of images, was employed to determine the penetration rate of the sealers into the lateral canals.

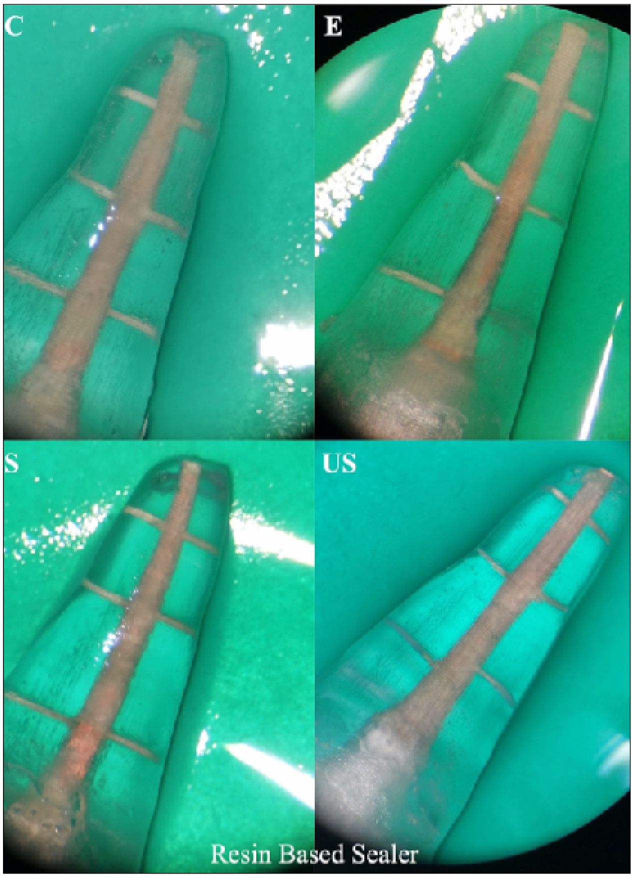


Fig. 1. The images of epoxy-resin based root canal sealer groups (17x). C: conventional activation; E: EDDY activation; S: Sonic activation; US: Ultrasonic activation.

In this study, we compared the effectiveness of various activation methods for root canal sealers regarding their capacity to enhance sealer penetration into the lateral canals (Fig. 1 and Fig. 2). No significant differences were observed among the activation methods for each root canal sealer, leading to the acceptance of the study's null hypothesis. In contrast to our findings, Arslan et al. (15) reported that ultrasonic and sonic activation applied to

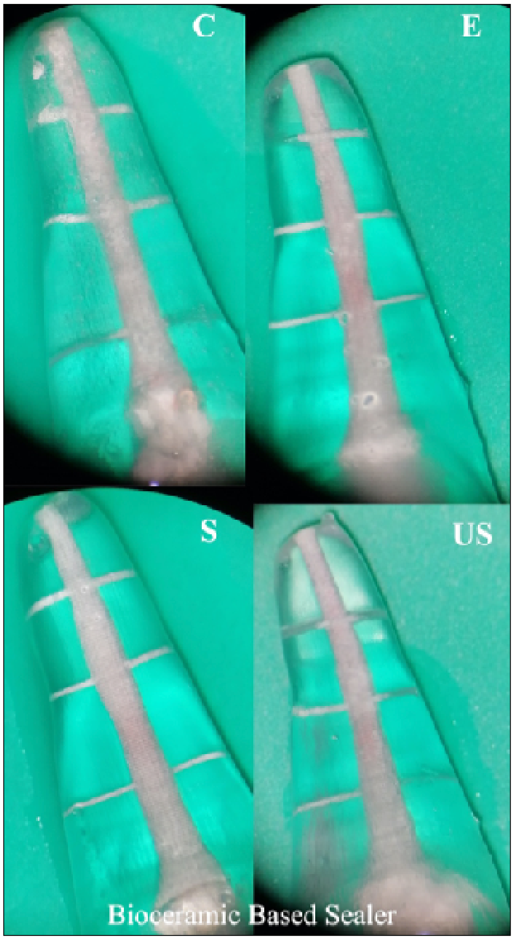


Fig. 2. The images of Bioceramic based root canal sealer groups (17x). C: conventional activation; E: EDDY activation; S: Sonic activation; US: Ultrasonic activation.

epoxy resin-based sealer increased sealer penetration into the lateral canals. We posit that the variation in lateral canal width created in these studies may account for this discrepancy.

Fernández et al. (17) examined the influence of resin and bioceramic-based root canal sealers on penetration into lateral canals. Regardless of the root canal filling technique, they found that resin-based root canal sealers exhibited greater effectiveness. Lopes et al. (14) conducted a study to investigate the penetration effect of resin and bioceramic-based root canal sealers at two different lateral canal widths (19). They reported no significant difference in penetration between the two root canal sealers. However, they observed that an increase in lateral canal diameter, especially when using bioceramic sealers, resulted in improved root canal sealer penetration. In our study, we observed that the penetration of the bioceramic root canal sealer in the sonic activation group (at the middle level) and the ultrasonic activation group (all root levels) was statistically superior compared to the resin-based root canal sealer. We attribute these discrepancies among the studies to potential variations in the diameter of created lateral canals and the choice between using plastic or natural teeth.

While it is indeed more convenient to create narrow canals in resin blocks or plastic teeth, it is essential to recognize that the surface texture can impact the flow properties of both gutta-percha and sealer (24). The use of resin-based teeth represents one of the limitations of this study. Furthermore, it's worth noting that lateral canals with a width of 150 nm were created in this study. Narrower lateral canals, measuring less than 150 nm in width, could potentially yield different outcomes regarding sealer penetration. Conducting further research to assess activation methods at various lateral canal diameters in natural teeth may offer valuable insights in this regard.

Conclusion

This study showed that activation methods and lateral canal location did not significantly affect the penetration of resin and bioceramic sealants into the lateral canals. Notably, in the groups where ultrasonic and sonic activation were applied, the bioceramic-based root canal sealer exhibited superior penetration efficiency into lateral canals compared to the resin-based root canal sealer.

Authorship Contributions: Concept: Ö.S., E.S.; Design: Ö.S., E.S., S.E.; Supervision: E.S.; Materials: Ö.S., E.S., S.E.; Data: Ö.S., E.S.; Analysis: Ö.S.; Literature search: Ö.S., E.S., S.E.; Writing: Ö.S., E.S., S.E.; Critical revision: E.S.

Use of AI for Writing Assistance: Not declared

Source of Funding: This work was supported by Çanakkale Onsekiz Mart University the Scientific Research Coordination Unit, Project number: THD-2022-4246.

Conflict of Interest: None declared.

References

1. Iqbal MK, Johansson AA, Akeel RF, Bergenholtz A, et al. A retrospective analysis of factors associated with the periapical status of restored, endodontically treated teeth. Int J Prosthodont 2003; 16: 31–8.
2. Schilder, H. Filling root canals in three dimensions. J Endod 2006; 32: 281–90.
3. De Deus QD. Frequency, location, and direction of the lateral, secondary, and accessory canals. J Endod 1975; 1: 361–6.
4. Weine FS. The enigma of the lateral canal. Dent Clin N Am 1984; 28: 833–52.

5. Cutright, DE, Bhaskar SN. Pulpal vasculature as demonstrated by a new method. Oral Surg Oral Med Oral Pathol 1969; 27: 678–83.
6. Venturi M, Di Lenarda R, Prati C, Breschi L. An in vitro model to investigate filling of lateral canals. J Endod 2005; 31(12): 877–81.
7. Villegas JC, Yoshioka T, Kobayashi C, Suda H. Obturation of accessory canals after four different final irrigation regimes. J Endod 2002; 28: 534–6.
8. Seltzer S, Bender IB, Ziontz M. The interrelationship of pulp and periodontal disease. Oral Surg Oral Med Oral Pathol 1963; 16: 1474–90.
9. Siqueira JF Jr, Rôças IN. Clinical implications and microbiology of bacterial persistence after treatment procedures. J Endod 2008; 34: 1291–301.e3.
10. Ricucci D, Siqueira JF Jr. Fate of the tissue in lateral canals and apical ramifications in response to pathologic conditions and treatment procedures. J Endod 2010; 36: 1–15.
11. Ricucci D, Loghin S, Siqueira JF Jr. Exuberant Biofilm infection in a lateral canal as the cause of short-term endodontic treatment failure: report of a case. J Endod 2013; 39: 712–8.
12. Candeiro GT, Correia FC, Duarte MA, Ribeiro-Siqueira DC, et al. Evaluation of radiopacity, pH, release of calcium ions, and flow of a bioceramic root canal sealer. J Endod 2012; 38: 842–5.
13. Wiesse PEB, Silva-Sousa YT, Pereira RD, Estrela C, et al. Effect of ultrasonic and sonic activation of root canal sealers on the push-out bond strength and interfacial adaptation to root canal dentine. Int Endod J 2018; 51: 102–11.
14. Lopes FC, Zangirolami C, Mazzi-Chaves JF, Silva-Sousa AC, et al. Effect of sonic and ultrasonic activation on physicochemical properties of root canal sealers. J Appl Oral Sci 2019; 27: e20180556.
15. Arslan H, Abbas A, Karatas E. Influence of ultrasonic and sonic activation of epoxy-amine resin-based sealer on penetration of sealer into lateral canals. Clin Oral Investig 2016; 20: 2161–4.
16. Almeida JF, Gomes BP, Ferraz CC, Souza-Filho FJ, et al. Filling of artificial lateral canals and microleakage and flow of five endodontic sealers. Int Endod J 2007; 40: 692–9.
17. Fernández R, Restrepo JS, Aristizábal DC, Álvarez LG. Evaluation of the filling ability of artificial lateral canals using calcium silicate-based and epoxy resin-based endodontic sealers and two gutta-percha filling techniques. Int Endod J 2016; 49: 365–73.
18. Venturi M. An ex vivo evaluation of a gutta-percha filling technique when used with two endodontic sealers: Analysis of the filling of main and lateral canals. J Endod 2008; 34: 1105–10.
19. Michelotto AL, Moura-Netto C, Araki AT, Akisue E, et al. Penetration of a resin-based filling material into lateral root canals and quality of obturation by different techniques. Braz Oral Res 2015; 29: 1–5.
20. Gurgel-Filho ED, Feitosa JP, Gomes BP, Ferraz CCR, et al. Assessment of different gutta-percha brands during the filling of simulated lateral canals. Int Endod J 2006; 39: 113–8.
21. Mena-Álvarez J, Sevrain JT, Zorita-García M, Rico-Romano C. Comparative analysis of the filling capacity of simulated lateral canals of two bioactive root canal sealers using warm gutta-percha technique. Appl Sci 2021; 11: 6270.
22. El Sayed M. Penetration of three endodontic sealers in simulated lateral canals during the lateral condensation technique: An in vitro study. Int J Dent 2022; 16: 2686247.
23. Karabucak B, Kim A, Chen V, Iqbal MK. The comparison of gutta-percha and Resilon penetration into lateral canals with different thermoplastic delivery systems. J Endod 2008; 34: 847–9.
24. DuLac KA, Nielsen CJ, Tomazic TJ, Ferrillo PJ Jr, et al. Comparison of the obturation of lateral canals by six techniques. J Endod 1999; 25: 376–80.
25. Kasahara E, Yasuda E, Yamamoto A, Anzai M. Root canal system of the maxillary central incisor. J Endod 1990; 16: 158–61.
26. Fidan, ME, Erdemir A. Effect of different irrigation activation techniques on irrigation penetration into the simulated lateral canals. Odontology 2023; 111: 132–41.
27. Xu T, Tay FR, Gutmann JL, Fan B et al. Micro-computed tomography assessment of apical accessory canal morphologies. J Endod 2016; 42: 798–802.
28. Tiago Ferreira, Wayne Rasband. ImageJ user guide IJ 1.46r. Available at: https://imagej.net/ij/docs/guide/user-guide.pdf. Accessed June 4, 2024.

ORIGINAL ARTICLE

Turk Endod J 2024;9(2):90–95
doi: 10.14744/TEJ.2024.78941

Evaluation of biomechanical properties of endodontic files with different pitch by finite element analysis

Mehmet Eskibağlar,[1] Serkan Erdem[2]

[1]Department of Endodontics, Faculty of Dentisry, Firat University, Elazığ, Türkiye
[2]Department of Mechanical Engineering, Faculty of Engineering, Firat University, Elazığ, Türkiye

Purpose: The purpose of this study was to evaluate the stress distribution of endodontic nickel-titanium (Ni-Ti) rotary files with different pitches in bending and torsion tests using finite element analysis (FEA).

Methods: Finite element models of superelastic Ni-Ti endodontic rotary instrument files with three different pitches (12, 15, and 18) were created using SolidWorks software. All endodontic files were modeled with the same length, apical diameter, and cross-sectional geometry. These models were transferred to ANSYS software for analysis. Tests to evaluate the flexibility and torsional stiffness of the files were performed using the FEA method, according to the ISO 3630-1 specification. The results obtained were calculated using the von Mises stress.

Results: The stiffness and maximum stress decreased as the pitch value increased. According to the test results, the 18 pitch file system exhibited higher flexibility than the 12 pitch and 15 pitch file systems when subjected to bending. In terms of torsional resistance, the 12 pitch rotary file showed higher torsional resistance than the 15 pitch and 18 pitch endodontic files.

Conclusion: Clinicians should be aware of the geometric differences in rotary files and use the appropriate file for clinical situations in addition to the manufacturer's instructions.

Keywords: Bending test; endodontic rotary file; finite element analysis; pitch; torsion test.

Introduction

Nickel-titanium (Ni-Ti) rotary instruments are widely used in endodontics. Ni-Ti rotary instruments allow for easy and quick preparation of the root canal system while providing more successful treatment than hand instruments (1). Ni-Ti instruments have greater flexibility and improved cutting ability compared to stainless steel instruments (2). Despite the advantages of Ni-Ti rotary file systems, these instruments are subject to fracture due to cyclic and torsional fatigue (2,3).

The two most important properties that affect the performance of Ni-Ti rotary instruments in clinical use are torsional stiffness and bending flexibility (4,5). Although there are many test methods in which these properties are evaluated, the ISO 3630-1 specification is frequently used in these studies. In this specification, the bending test was performed by holding the file 3 mm from the tip and bending it 45°. The torsion test was performed by holding the file 3 mm from the tip and rotating the shaft clockwise (6). Enhancing the geometric designs leads to better ef-

Cite this article as: Eskibağlar M, Erdem S. Evaluation of biomechanical properties of endodontic files with different pitch by finite element analysis. Turk Endod J 2024;9:90-95.
Correspondence: Mehmet Eskibağlar. Faculty of Dentisry, Firat University, Elazığ, Türkiye
Tel: +90 424 – 237 89 85 e-mail: meskibaglar@firat.edu.tr
Submitted: April 18, 2024 Revised: June 04, 2024 Accepted: June 06, 2024 Published: August 29, 2024

ficiency of endodontic files. The influence of various geometric designs on the efficiency of endodontic files has been primarily studied through the analysis of the cyclic fatigue resistance of instruments in endodontic literature (7,8). However, the cyclic fatigue test does not assess geometric parameters such as pitch and apical diameter, which are associated with the bending and torsional behavior of instruments (9). The mechanical behavior and stress distributions of Ni-Ti rotary instruments subjected to various conditions can be determined mathematically using finite element analysis (10).

The purpose of this study is to evaluate the biomechanical properties of the variable pitch values of the Ni-Ti rotary file system, the design of which belongs to us, under ISO 3630-1 boundary conditions.

Materials and Methods

Ni-Ti rotary instrument files, which were not commercially available, were designed with convex triangular cross-section, ISO #30 apical diameter, 0.04 taper angle, and 12, 15, and 18 pitch. These models were 3D modeled using SolidWorks software (Dassault Systems SA, Concord, MA, USA) with a working length of 16 mm and were saved with *.prt extensions (Fig. 1). The resulting Ni-Ti rotary file models were saved in Parasolid (*.x_t) extension and prepared for use in the ANSYS Workbench 2019 R1 software (ANSYS, Inc., Canonsburg, PA, USA).

The Ni-Ti material properties were selected in the Ansys Workbench software for the properties of the Ni-Ti rotary file to be used in the ISO-3630-1 tests (11). The mechanical properties of the materials are listed in Table 1 (12).

In ANSYS Workbench software, the Ni-Ti file axes were positioned using the -x axis. The Ni-Ti rotary file models were meshed using quadratic elements (Fig. 2). As a result

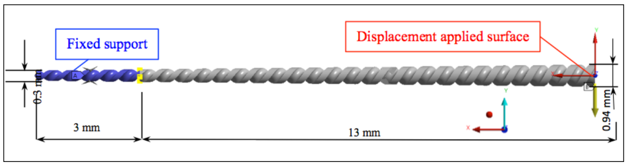


Fig. 1. Sample boundary condition and dimensioned Ni-Ti file model.

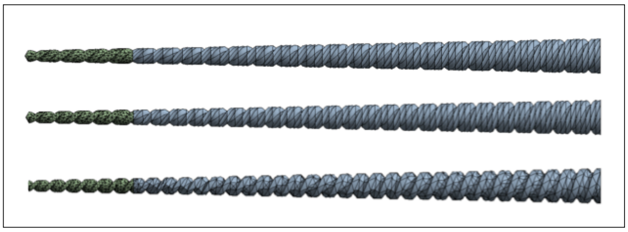


Fig. 2. Mesh structure of the analysed endodontic file **(a)** 12 pitch, **(b)** 15 pitch, **(c)** 18 pitch.

of the meshing process, the 12-15-18 pitch models contained 4997 node-1518 elements, 4694 node-1474 elements, and 7379 node-3795 elements.

Analyses of the Ni-Ti rotating file systems were performed using the ANSYS Workbench software according to the ISO 3630-1 boundary conditions (10). The bending test boundary conditions were established by providing fixed support on the apical side of the file and 13 mm displacement on the coronal side to provide a bending angle of 45° along the -y axis, as shown in Figure 1. To create the fixed support condition, the model was cut 3 mm from the apical side using the SolidWorks software and divided into two parts. In ANSYS Workbench software, a bonded connection boundary condition was applied to allow the two parts to move as one piece. A free boundary condition was applied to the coronal side of the model along the -x and -z axes (Fig. 3).

To observe the torsional behavior of the models, a boundary condition was applied as shown in Figure 4. Unlike in

Table 1. Material properties for the Ni-Ti rotary file used in the analysis

Parameter	Description	Value
E	Young's modulus	60000 MPa
v	Poisson ratio	0.36
K	Bulk modulus	71429 MPa
G	Shear modulus	22059 MPa
σ_s^{AS}	Starting stress value for the forward phase transformation	520 MPa
σ_f^{AS}	Final stress value for the forward phase transformation	600 MPa
σ_s^{SA}	Starting stress value for the reverse phase transformation	300 MPa
σ_f^{SA}	Final stress value for the reverse phase transformation	200 MPa
$\bar{\varepsilon}_L$	Maximum residual strain	0.07 mm/mm
α	Parameter measuring the difference between material responses in tension and compression	0
E_s	Elastic modulus of the full martensite phase If 0 or undefined, the martensite and austenite phases share the same elastic modulus	60000 MPa

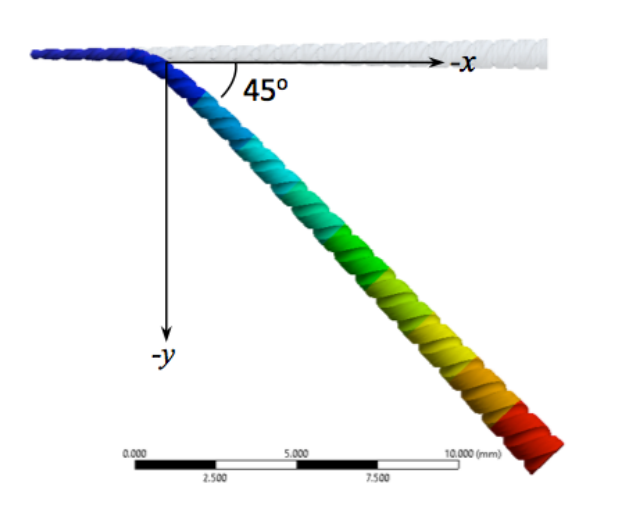


Fig. 3. 45° displacement in -y axis to the endodontic file model.

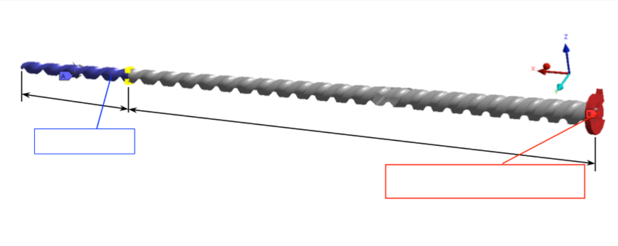


Fig. 4. Application of the rotation moment along the -x axis to the endodontic file model.

the bending test, a torque of 2 Nmm was applied on the -x axis from the coronal side of the model.

Results

Bending Test

In accordance with the ISO 3630-1 boundary condition, a fixed support of 3 mm length was applied to the apical end of the file on rotary file models with different pitch values. The Ni-Ti rotary file was then forced to bend at a 45° angle to the coronal side of the file. The maximum von Mises (vM) stress occurred in a similar pattern for the Ni-Ti rotary files subjected to bending. The maximum vM stress in all Ni-Ti rotary files was 600-900 MPa with a linear increase up to ~10° bending angle and remained constant up to ~35° bending angle. When the bending angle was increased to 45°, the stress again increased linearly and was ~1500 MPa for the 12 pitch Ni-Ti rotary file, ~1200 MPa for the 15 pitch Ni-Ti rotary file, and ~1000 MPa for the 18 pitch Ni-Ti rotary file.

The reaction bending moment behavior of the Ni-Ti rotary files for 45° bending was similar for each file. Reaction bending moments for ~10°-15° bending were obtained as

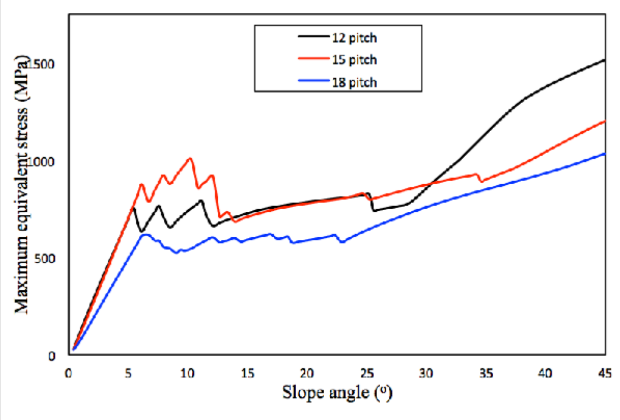


Fig. 5. Effect of change in pitch on bending angle behaviour- maximum equivalent stress.

3 Nmm for 12 pitch, 2.5 Nmm for 15 pitch, and 2 Nmm for 18 pitch files with a linear increase. When the bending angle was increased by 45°, the increase in reaction bending moment was again linear, but the increase decreased and was obtained as ~5.5 Nmm for 12 pitch, ~4.5 Nmm for 15 pitch, and 3.5 Nmm for 18 pitch.

The maximum vM stress versus bending angle is shown in Figure 5, and the reaction bending moment versus bending angle is shown in Figure 6.

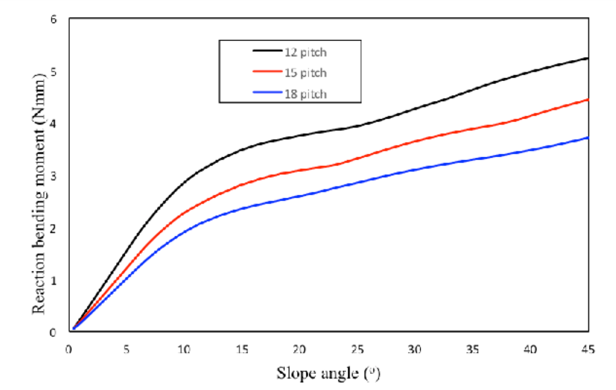


Fig. 6. Effect of change in pitch on bending angle- Reaction bending moment behavior.

Torsion Test

A torque of 2 Nmm was applied to the Ni-Ti rotary file models in accordance with the ISO 3630-1 boundary conditions. As a result of this test, the maximum vM stress values of the 12 and 15 pitch models were obtained as ~720 MPa, with a linear increase. In the 18 pitch file, the maximum vM stress was obtained as ~600 MPa with a linear increase at 1.6 Nmm torque and was then found to be constant. Figure 7 shows the vM stress values against the torsion test, where the red areas represent the damage stresses. The highest stress was localized on the outer sur-

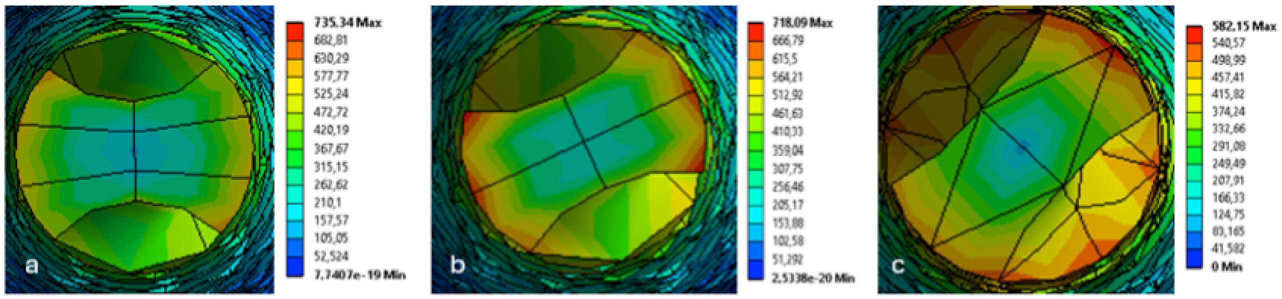


Fig. 7. Max vM stress according to the number of pitches in torsion test a) 12 pitch, b) 15 pitch, c) 18 pitch.

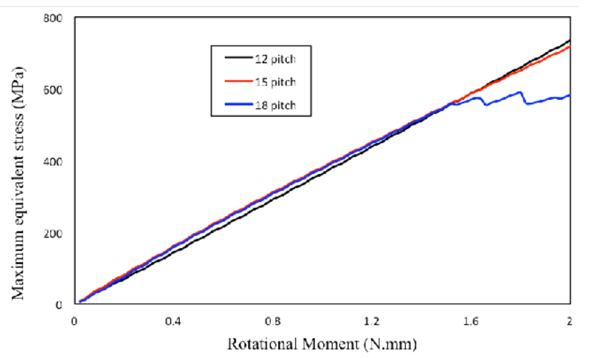


Fig. 8. Effect of pitch on torque- maximum equivalent stress behavior.

face of the Ni-Ti file. The maximum vM stress is obtained as a function of the applied torque, as shown in Figure 8.

Discussion

The performance of Ni-Ti rotary instruments with a variable pitch was evaluated under bending and torsion loads using FEA analysis in this study. FEA allows for the assessment of the impact of different geometrical parameters on the mechanical properties of materials through computational processing (13). This method enables the calculation of stress distributions and concentrations, minimizes uncontrollable variables, and ensures the repeatability of the test conditions for analysis (14,15). Owing to its effectiveness in analyzing the stresses that arise during the use of Ni-Ti rotary files, FEA is commonly utilized in the field of endodontics (16,17). Therefore, we employed the FEA method to assess the mechanical performance of Ni-Ti rotary files in our study.

The Ni-Ti rotary file systems analyzed in this study were selected as superelastic materials. In this material behavior, when the superelastic material is subjected to a tensile test, it undergoes a certain deformation. However, when the force on it is removed, it returns the deformation by following a different path (18). In addition, various thermomechanical processes have been applied to Ni-Ti rotary file systems to increase their strength (19,20).

However, because this study evaluated the effect of different pitches on bending and torsional stiffness, differences in the material properties of the Ni-Ti rotary files were not considered.

The helical flute angle is formed by the cutting edge and a cross-section perpendicular to the long axis of the file, and the pitch is the distance between the two cutting edges in the lateral view (21). The pitch of an instrument is significant because it influences flexibility and cutting efficiency (22). A decrease in the value of pitch and an increase in the number of flutes increase the working cutting edge length of a file, which improves the cutting efficiency of the instrument, increases the bending stiffness, and reduces stress (3). Instruments with increased pitch allow for debris removal and flexibility; however, the risk of torsional failure increases because of the distribution of high stress (23). A Ni-Ti rotary file system generally has 5-15 pitch (3). In previous studies that used finite element models to investigate the effect of pitch length, a short, decreased pitch (increasing threads) reduced the stiffness of the files (3,22). Our results are also supported by previous studies that used finite element models in which the short pitch had a higher torsional fracture resistance (3,22,23). In addition, short pitch files may be preferred when high flexibility is expected from files in clinical practice.

Changes in pitch affect Ni-Ti rotary files with different cross-sectional shapes. Instruments with square cross-sections were the least affected, whereas those with rectangular cross-sections were the most affected by the pitch value. The different cross-sections of the Ni-Ti rotary file affected the results (21). Our study changing the pitch value may have affected the results by causing the cross-sectional geometry to differ between files. Because our study focused on pitch variability, cross-sectional geometry was ignored. This is one of the limitations of this study.

However, in models with convex triangular cross-sections, the maximum stress occurred at the periphery (or border) of the cross-sections and was often located near the base or “bottom” of the flute. One of the factors that may affect these stresses is that only the working part of the file was modeled in our study. Testing the file together with the shaft may be one of the factors affecting the results of this study. This is one of the limitations of this study.

The tests in this study were performed according to the boundary conditions of ISO 3630-1 in order to standardize the Ni-Ti rotary file studies evaluated by FEA (6,24,25). Increasing the pitch value of the Ni-Ti rotary files of the same length resulted in more material being removed from the Ni-Ti rotary file. In the bending test, increasing the pitch value of the Ni-Ti rotary files led to a decrease in the force required to bend the files. Consequently, the maximum vM stress decreased as the pitch increased. The results obtained in our study are consistent with those of similar studies (8,23). Furthermore, based on the results obtained in our study, it is recommended to use rotary files with a higher pitch value to shape curved root canal systems (8). From a clinical perspective, a 12-pitch file may exert more force on the root canal walls because of its higher stiffness causing complications such as perforation or zip formation in the root canal system. However, when rotary files are placed in the root canal system, the boundary conditions may change because of the changes in the contact points on the root canal walls.

In the torsion test, the effect of the instrument connection was simulated by fixing the endodontic rotary file 3 mm from the apical end and applying a torque of 2 Nmm. According to the test results, the torsional moment of the 18 pitch rotary file system was lower than those of the others. Increasing the pitch reduces the cross-sectional area for the same length, which reduces the inertia and therefore the stress in the file. This is also reflected in the stress behavior. These results are consistent with those of other studies showing that torsional stiffness is dependent on cross-sectional geometry (26,27). In addition, the stress levels in tools under torsion cannot be predicted from the stiffness response alone. A combination of factors such as the cross-sectional geometry of the files, their mechanical properties, where the stress is applied and where the deformation is measured, will influence the stress (28).

Conclusion

For biomechanical preparation of the root canal system, clinicians may prefer a rotary file system with a higher pitch value, depending on the bending and torsional behavior, considering the stress to which the Ni-Ti rotary files will be subjected. In addition, it should be noted that the low pitch value in the preferred Ni-Ti rotary file system may make file movement more difficult.

Authorship Contributions: Concept: M.E., S.E.; Design: S.E.; Supervision: M.E., S.E.; Fundings: M.E., S.E.; Materials: S.E.; Data: S.E.; Literature search: M.E.; Writing: M.E., S.E.; Critical revision: M.E., S.E.

Use of AI for Writing Assistance: Not declared

Source of Funding: None declared.

Conflict of Interest: None declared.

References

1. Iandolo A, Abdellatif D, Pantaleo G, et al. Conservative shaping combined with three-dimensional cleaning can be a powerful tool: Case series. J Conserv Dent 2020; 23: 648–52. [CrossRef]
2. Roda-Casanova V, Pérez-González A, Zubizarreta-Macho Á, et al. Fatigue analysis of NiTi rotary endodontic files through finite element simulation: Effect of Root canal geometry on fatigue life. J Clin Med 2021; 10: 5692. [CrossRef]
3. Versluis A, Kim HC, Lee W, et al. Flexural stiffness and stresses in nickel-titanium rotary files for various pitch and cross-sectional geometries. J Endod 2012; 38: 1399–403. [CrossRef]
4. Barbosa FO, Gomes JA, de Araújo MC. Fractographic analysis of K3 nickel-titanium rotary instruments submitted to different modes of mechanical loading. J Endod 2008; 34: 994–8. [CrossRef]
5. Plotino G, Grande NM, Cordaro M, et al. A review of cyclic fatigue testing of nickel-titanium rotary instruments. J Endod 2009; 35: 1469–76. [CrossRef]
6. Chien PY, Walsh LJ, Peters OA. Finite element analysis of rotary nickel-titanium endodontic instruments: A critical review of the methodology. Eur J Oral Sci 2021; 129: e12802. [CrossRef]
7. Faus-Llácer V, Kharrat NH, Ruiz-Sánchez C, et al. The effect of taper and apical diameter on the cyclic fatigue resistance of rotary endodontic files using an experimental electronic device. Appl Sci 2021; 11: 863. [CrossRef]
8. Kwak SW, Ha JH, Lee CJ, et al. Effects of pitch length and heat treatment on the mechanical properties of the glide path preparation instruments. J Endod 2016; 42: 788–92. [CrossRef]
9. Hülsmann M. Research that matters: Studies on fatigue of rotary and reciprocating NiTi root canal instruments. Int Endod J 2019; 52: 1401–2. [CrossRef]
10. Basheer Ahamed SB, Vanajassun PP, Rajkumar K, et al. Comparative evaluation of stress distribution in experimentally designed nickel-titanium rotary files with varying cross sections: A finite element analysis. J Endod 2018; 44: 654–8. [CrossRef]

11. International Organization for Standardization. Root canal instruments—Part DRC. 1: General requirements and test methods. Available at: https://www.iso.org/obp/ui/#iso:std:iso:3630:-1:ed-2:v1:en. Accessed Jul 19, 2024.
12. de Arruda Santos L, López JB, de Las Casas EB, de Azevedo Bahia MG, Buono VT. Mechanical behavior of three nickel-titanium rotary files: A comparison of numerical simulation with bending and torsion tests. Mater Sci Eng C Mater Biol Appl 2014; 37: 258–63. [CrossRef]
13. Lee MH, Versluis A, Kim BM, et al. Correlation between experimental cyclic fatigue resistance and numerical stress analysis for nickel-titanium rotary files. J Endod 2011; 37: 1152–7. [CrossRef]
14. Srirekha A, Bashetty K. Infinite to finite: An overview of finite element analysis. Indian J Dent Res 2010; 21: 425–32. [CrossRef]
15. Díaz-Flores García V, Pimienta Vázquez MI, Tejedor B, et al. Comparative study of torsional and bending stress in NiTi, graphene, and GUM metal endodontic files by finite element analysis. Comput Biol Med 2024; 170: 108017. [CrossRef]
16. Scattina A, Alovisi M, Paolino DS, et al. Prediction of cyclic fatigue life of nickel-titanium rotary files by virtual modeling and finite elements analysis. J Endod 2015; 41: 1867–70. [CrossRef]
17. Roda-Casanova V, Zubizarreta-Macho Á, Sanchez-Marin F, et al. Computerized generation and finite element stress analysis of endodontic rotary files. Appl Sci 2021; 11: 4329. [CrossRef]
18. Martins SCS, Garcia PR, Viana ACD, Buono VTL, et al. Off-centered geometry and influence on NiTi endodontic file performance evaluated by finite element analysis. J Mater Eng 2020; 29: 2095–102. [CrossRef]
19. Martins JNR, Silva EJNL, Marques D, et al. Characterization of the file-specific heat-treated ProTaper Ultimate rotary system. Int Endod J 2023; 56: 530–42. [CrossRef]
20. Topçuoğlu HS, Topçuoğlu G, Kafdağ Ö, et al. Effect of two different temperatures on resistance to cyclic fatigue of one Curve, EdgeFile, HyFlex CM and ProTaper next files. Aust Endod J 2020; 46: 68–72. [CrossRef]
21. Liang Y, Yue L. Evolution and development: engine-driven endodontic rotary nickel-titanium instruments. Int J Oral Sci 2022; 14: 12. [CrossRef]
22. Al Raeesi D, Kwak SW, Ha JH, et al. Mechanical properties of glide path preparation instruments with different pitch lengths. J Endod 2018; 44: 864–8. [CrossRef]
23. Baek SH, Lee CJ, Versluis A, et al. Comparison of torsional stiffness of nickel-titanium rotary files with different geometric characteristics. J Endod 2011; 37: 1283–6. [CrossRef]
24. Miccoli G, Cicconetti A, Gambarini G, et al. A new device to test the bending resistance of mechanical endodontic instruments. Appl Sci 2020; 10: 7215. [CrossRef]
25. Só GB, Siocheta G, Calefi P, et al. Cyclic and torsional fatigue resistance of a new rotary file on a rotary and reciprocating motion. Microsc Res Tech 2023; 86 :1635–41. [CrossRef]
26. Ismail AG, Zaazou MHA, Galal M, et al. Finite element analysis comparing WaveOne Gold and ProTaper Next endodontic file segments subjected to bending and torsional load. Bull Nat Res Cent 2019; 43: 194. [CrossRef]
27. Ninan E, Berzins DW. Torsion and bending properties of shape memory and superelastic nickel-titanium rotary instruments. J Endod 2013; 39: 101–4. [CrossRef]
28. Kim HC, Kim HJ, Lee CJ, et al. Mechanical response of nickel-titanium instruments with different cross-sectional designs during shaping of simulated curved canals. Int Endod J 2009; 42: 593–602. [CrossRef]

ORIGINAL ARTICLE

Turk Endod J 2024;9(2):96–102
doi: 10.14744/TEJ.2024.97658

Evaluation of the effect of Mozart's music on stress, anxiety, and dexterity levels of dental students in preclinical endodontic training using a haptic virtual reality simulator

Sıla Nur Usta, Eda Doğuş, Zeliha Uğur Aydin

Department of Endodontics, Gulhane Faculty of Dentistry, Health Sciences University, Ankara, Türkiye

Purpose: To assess the stress and anxiety levels of 3rd-year students in preclinical training along with their success rates under the background of Mozart's music using a haptic virtual reality simulator (HVRS).

Methods: Sixty 3rd-year dentistry students enrolled in preclinical endodontic training were selected based on the inclusion criteria. Participating students were randomly divided into two groups according to whether Mozart's music was used during the access cavity preparation using HVRS. Stress and anxiety levels were evaluated with the Stress-VAS 1 and 2 scales and STAI S and T questionnaires, respectively. Manual dexterity was measured based on the target progress, accuracy, target volume, and outside volume. Data were analyzed with Fisher's exact and Mann-Whitney U tests and the square of the Spearman linear coefficient.

Results: There was no statistically significant difference between genders regarding stress and anxiety levels ($p > 0.05$). Music significantly reduced stress and anxiety levels and enhanced manual dexterity ($p < 0.05$). A significant negative association was observed between the target progress and Stress-VAS 2 ($p < 0.05$), whereas the correlation did not differ between accuracy and Stress-VAS 2 ($p > 0.05$).

Conclusion: Mozart's music positively affected stress and anxiety levels along with the manual dexterity of students in preclinical endodontic training using HVRS.

Keywords: Anxiety; endodontics; music; stress; virtual reality.

Introduction

Preclinical training, which usually occurs during the 2nd and 3rd year of study, is an essential component of dental education. Students can learn basic dentistry applications and gain experience by developing the foundational knowledge and skills required for clinical practice (1). Consequently, this phase mainly focuses on providing a combination of theoretical (classroom-based) learning, hands-on laboratory exercises, and simulated clinical experiences (2). As well as in other dentistry fields, it is also aimed at training versatile and self-confident students by teaching various treatments within the scope of preclinical endodontic training (3).

The essential goal of endodontic preclinical training is to enable students to practice basic endodontic applications such as access cavity preparation, root canal instrumenta-

Cite this article as: Usta SN, Doğuş E, Aydın-Ugur Z. Evaluation of the effect of Mozart's music on stress, anxiety, and dexterity levels of dental students in preclinical endodontic training using a haptic virtual reality simulator. Turk Endod J 2024;9:96-102.
Correspondence: Sıla Nur Usta. Gulhane Faculty of Dentistry, Health Sciences University, Ankara, Türkiye
Tel: +90 312 – 304 20 00 e-mail: silandeniz29@gmail.com
Submitted: June 07, 2024 Revised: July 13, 2024 Accepted: July 16, 2024 Published: August 29, 2024

tion, obturation, and restoration of endodontically treated teeth (4). Moreover, this training could help detect and prevent possible complications, test suitable working conditions, and shorten the time required for clinical treatments (5,6). Extracted human teeth have been used for many years in preclinical training to achieve present goals (7). However, over the years, some concerns regarding extracted teeth, such as being difficult to obtain, the risk of cross-infection, anatomical variability, and ethical issues, have popularized the use of artificial tooth models (8,9). Although artificial models can overcome the present limitations of extracted teeth, they cannot replace the requirement to learn with natural teeth as part of endodontic training curriculum since they cannot stimulate clinical conditions (9). Additionally, nowadays, advances in technology have enabled the constitution of new educational models in addition to traditional preclinical training (10).

One of the contemporary preclinical educational approaches, virtual reality, refers to a human-computer interface that provides three-dimensional visualization and control of applications by evoking a sensory experience similar to a real clinic setting (11). The haptic virtual reality simulators (HVRS) facilitate students to perform applications realistically and interactively as many times as possible without the need for any material (12). In order to increase realism, haptic devices that ensure tactile sensations to the users have been developed. The HVRS provides feedback by forces, vibrations, or motions (11,13), and therefore these simulators are used in preclinical endodontic training (14). Students can open the access cavities in teeth with different root canal anatomy by feeling the enamel and dentine tissues, and they also can obtain the errors and deficiencies as a result of the applications (15).

Although preclinical training is aimed to be facilitated with new technological education models, the transition period from theoretical education to the preclinical stage still poses challenges (16). Especially the lack of theoretical knowledge or the inability to adequately reflect the learned information in preclinical training can cause high stress and anxiety levels in dentistry students (17,18). Consequently, this stressful and anxious psychological state may impact students' learning and practice skills (19). In order to create a relaxed atmosphere, background music therapy can be preferred since it is an easily accessible, applicable, and inexpensive method in preclinical training (20,21). It was reported that music helps individuals focus on tasks requiring concentration (22). Moreover, it was also indicated that Mozart's music, in particular, enhances the learning of spatiotemporal rotation tasks by activating related brain areas (23).

The impact of background music on stress reduction and practical performance in preclinical training has been investigated previously (18,24). However, to our knowledge, there is no study that evaluates the stress and anxiety levels of students along with manual dexterity using HVRS under background music in preclinical endodontic training. Since HVRSs could be experienced by students as relatively new and unusual, the possible stress levels and learning abilities need to be assessed. Thus, this study aimed to assess the stress and anxiety levels of 3rd-year students in preclinical training along with their success rates under the background of Mozart's music using an HVRS. The null hypothesis was that the background of Mozart's music would not affect stress and anxiety levels and manual dexterity.

Materials and Methods

This study was approved by the University's ethical board (No.: 2023-37). The sample size estimation was done based on a similar study in the literature, with the level of significance at 5% and the power of the study at 90% by G*Power 3.1.9.2 software program. Consequently, the minimum required total number of students was found to be 60 (25).

All 3rd-year dentistry students enrolled in preclinical endodontic training scheduled by the Department of Endodontics were informed regarding the scope of the study. Afterwards, seventy voluntary students were tested in terms of inclusion criteria. The inclusion criteria for the participating students are as follows: being a 3rd-year dentistry student aged 20-21, having experience of access cavity preparation using extracted human teeth, not taking any medication for anxiety, depression, or systemic illness, having at least a moderate ability to utilize a computer, and not having intolerance against music. The stress level was evaluated using a 10 cm stress visual analog scale (Stress-VAS 1) (26). The level of stress was determined from 0 (no stress) to 10 (worst possible stress). A threshold of 6 was assigned for the description of the student as stressful (27), and the students who had 6 or more were excluded. Moreover, computer usage skills were assessed with an adapted computer literacy self-assessment (14). Based on the primary evaluation, sixty students were included, and signed written consents were obtained. Demographic data of each participant (age and gender) were recorded.

All interventions were conducted in the simulation laboratory of the University. In the first session, trained endodontists (SNU and ED) gave a brief lecture regarding the use of HVRSs (VirTeaSy Dental©, France), and a practical demonstration was conducted by the same endodontist (ED) for selected students in divided groups of six students each. In this sense, an access cavity preparation of the mandibular canine was performed. Thereafter, students exercised the same preparation on the HVRS three times within a week in the same conditions. No time restriction was applied to allow the students to feel relaxed and learn the basic properties of the simulator adequately.

Students were divided into two groups randomly (https://www.randomizer.org/) to evaluate the effect of background Mozart music on anxiety and practical dexterity levels. Students in Group 1 performed cavity preparation without any musical effect. On the other hand, students in Group 2 listened to the Mozart Sonata for Two Pianos in D major, K. 448 with headphones while performing the same training since Mozart's music can be easily implemented for reducing anxiety and improving learning ability (23,28). Due to the fact that there are two simulators in the laboratory, one student from Groups 1 and 2 carried out the applications with simulators concurrently in routine preclinical endodontic training sessions. In Group 1, the tempo of the original version of the song (138 beats/min) was converted to 68 beats/min, and the volume was set to 50 dB (29).

The VirTeaSy dental simulator consists of a touchscreen and three-dimensional (3D) screen that allow the visualization of high-resolution views of teeth, endodontic instruments, and dental tools (30). Below the 3D screen, there are haptic and mirror tools and a 3D mouse. Students in the groups performed the access cavity preparation of the mandibular canine within ten minutes using a simulator (Fig. 1). The output data included the following parameters: surgery time (the total time of performance (second)), drilling time (the time of using the handpiece (second)), target progress (the percentage (%) of the area that should be removed), accuracy (% of the area that should not be removed), target volume (the area (mm³) that should be removed), and outside volume (the area (mm³) that should not be removed) (Fig. 2). All results of the performance process of each student were recorded and evaluated regarding manual dexterity. The assessments were only done according to the output data received from the software to ensure standardization and avoid any bias.

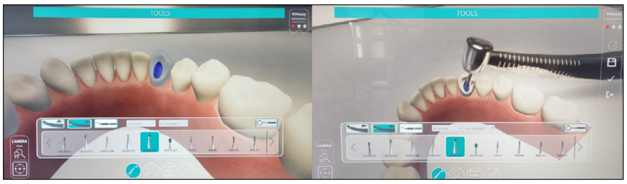


Fig. 1. Demonstration of the preparation of access cavity of mandibular canine tooth.

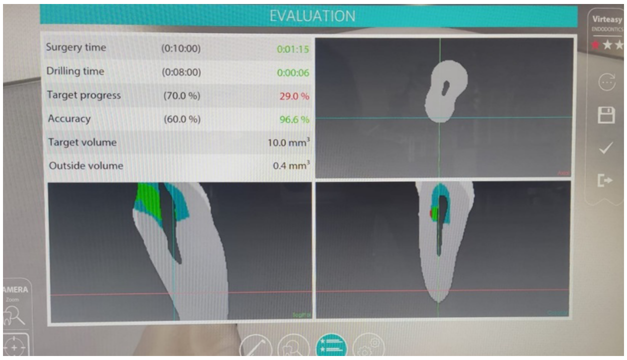


Fig. 2. Parameters obtained from haptic virtual reality simulator.

Steady-State Anxiety Inventory (STAI (S and T)), which was developed by Spielberg et al. (31), was used to measure the anxiety levels of students. Whereas STAI-S indicates the anxiety level at a particular moment, STAI-T demonstrates the general perspective of a person's emotional state. STAI-S and T contain 20 items rated one to four. The higher scores indicate higher anxiety. The Turkish adaptation, validity, and reliability of STAI were created by Öner et al. (32). Accordingly, STAI-S was asked to be replied to just after performing the access cavity preparation along with Stress-VAS (Stress-VAS 2) to measure the post-training stress level. STAI-T was utilized before training to evaluate the general condition of the students to detect any possible extraordinary anxiety level that may impact the study's outcome.

Table 1. Stress-VAS 1 and 2 values regarding gender and groups

	Stress-VAS 1	Stress-VAS 2	p Value
Female	$3.53 \pm 0.97^{a,1}$	$2.93 \pm 1.55^{a,1}$	0.43
Male	$3.43 \pm 1.07^{a,1}$	$3.2 \pm 1.9^{a,1}$	0.83
Inter-gender p value	0.88	0.84	
Group 1	$3.6 \pm 1.06^{a,1}$	$3.83 \pm 1.85^{a,1}$	0.76
Group 2	$3.36 \pm 0.96^{a,1}$	$2.3 \pm 1.17^{b,2}$	0.006
Inter-group p value	0.78	0.015	

Different superscript lowercase letters in the same row indicate a statistically significant difference ($p < 0.05$). Different superscript numbers in the same column indicate a statistically significant difference ($p < 0.05$).

Statistical Analysis

All statistical analyses were done using IBM SPSS (SPSS Inc., Chicago, IL, USA) version 26. Normality of variables was determined by the Kolmogorov-Smirnov test since the number of samples per group was 30. Stress-VAS 1 and 2 values were compared by Pearson chi-square/Fisher's exact tests. Parameters such as surgery time, target progress, target volume, and outside volume were analyzed using Mann-Whitney U test between Group 1 and 2. Among two groups, drilling time, accuracy, STAI-S, and STAI-T values were compared by independent t-test. The correlation between accuracy, target progress, and Stress-VAS 2 was evaluated using the square of the Spearman linear coefficient. The significance level was 5%.

Results

Thirty (50%) of the 60 selected students in this study were female, and 30 (50%) were male. The mean age was 20.38. Stress-VAS 1 and Stress-VAS 2 values did not differ regarding gender ($p > 0.05$), indicating a random distribution as shown in Table 1. Moreover, while Stress-VAS 1 values were similar between groups ($p < 0.05$), Group 1 had significantly higher Stress-VAS 2 values compared to Group 2 ($p < 0.05$) (Table 1).

There was no significant difference between Group 1 and Group 2 in terms of drilling time, surgery time, target volume, and outside volume ($p > 0.05$) (Table 2). On the other hand, accuracy and target process values were significantly higher in Group 2 compared to Group 1 ($p < 0.05$) (Table 2).

Table 2. Output data obtained from VR simulator in terms of manual dexterity

	Group 1	Group 2
Surgery time (sec)	247.83[a]	243.13[a]
Drilling time (sec)	82.9[a]	79.96[a]
Target progress (%)	67.12[a]	82.57[b]
Accuracy (%)	76.36[a]	85.54[b]
Target volume (mm^3)	23.01[a]	26.74[a]
Outside volume (mm^3)	8.35[a]	13.37[a]

Different superscript lowercase letters in the same row indicate a statistically significant difference ($p < 0.05$).

Table 3. STAI-S and STAI-T values regarding gender and groups

	STAI-S	STAI-T
Female	37.06 ± 10.35[a]	44.2 ± 7.44[a]
Male	37.2 ± 9.47[a]	42.6 ± 9.11[a]
Inter-gender p value	0.93	0.47
Group 1	41.27 ± 10.78[a]	42.60 ± 7.91[a]
Group 2	33.07 ± 6.77[b]	44.27 ± 8.71[a]
Inter-group p value	0.001	0.44

Different superscript lowercase letters in the same column indicate a statistically significant difference ($p < 0.05$).

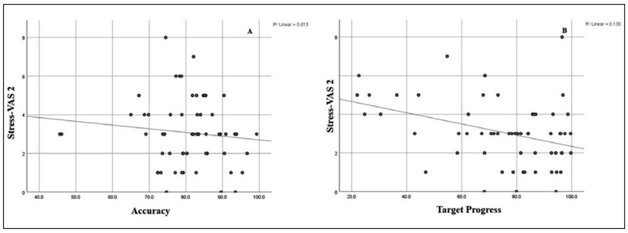


Fig. 3. Association between accuracy and Stress-VAS 2 **(a)**, association between the target progress and Stress-VAS 2 **(b)**.

STAI-S and STAI-T values did not differ regarding gender ($p > 0.05$) (Table 3). Furthermore, although Group 1 had significantly higher STAI-S values compared to Group 2, STAI-T values were identical between groups as presented in Table 3.

A significant negative association was observed between the target progress and Stress-VAS 2 (correlation coefficient = -0.313, $p < 0.05$). However, the correlation between accuracy and Stress-VAS 2 was not statistically significant (correlation coefficient = -0.117, $p > 0.05$). Associations are shown in Figure 3.

Discussion

Preclinical endodontic training is a core process where dental students can develop their manual dexterity and have the opportunity to practice in different clinical scenarios along with theoretical education within the scope of endodontic treatments (33). Students may experience high levels of anxiety and stress during this challenging and stressful period (34). In this sense, background Mozart's music could be beneficial for reducing undesirable stress parameters and increasing the success rate in applications by creating a comfortable and relaxing working environment (35). Thus, this study aimed to evaluate the possible effects of Mozart's music in preclinical endodontic training using HVRS. Based on the findings, the null hypothesis was rejected since the background music was associated with low levels of stress and anxiety and high accuracy values.

In this study, the HVRS was used since these simulators are relatively new preclinical educational tools that can simulate the clinical condition more accurately. In addition, the environment, used materials, and selected tooth for access cavity preparation were the same for each student; therefore, standardization was ensured completely, and possible external factors that may affect the results were eliminated. Moreover, all selected students had previously performed access cavity preparation with extracted human teeth and had experience using an HVRS in preclinical restorative training. Hence, the stress and anxiety levels that can be caused by using a new tool or performing a new application were minimized. Furthermore, a mandibular canine was used for access cavity preparation since it has less complex anatomy compared to the premolars and/or molars (36).

It has been shown that music therapy has a positive effect on patients' emotional states during dental treatments and also reduces the stress levels of clinicians during demanding procedures or busy schedules as well as undergraduate dental students who perform preclinical training (18,37,38). Similar to the present findings of this study, Felszeghy et al. (24) also showed that music reduced stress and increased the motivation of dental students to learn and practice in preclinical cariology training. Moreover, Varma et al. (18) indicated a strong positive relation between stress and background music in the preclinical laboratory. In these two studies, various types of music were used. However, different types may cause variable feelings, behaviors, and cognitive skills in students. Thus, the particular Mozart sonata was listened to by students since it impacts concentration and efficiency in tasks as well as reduces stress and anxiety levels as previously shown (25).

It is essential for the maintenance of the mental and physical health of the students who enroll in preclinical endodontic training, which includes various compelling tasks. In this sense, educational models are continuously evolving through the development of technology and enhanced experience of dental educators to ensure relaxed and comfortable working conditions (39). This is the first study that evaluates the stress and anxiety levels of students along with manual dexterity using HVRSs as a relatively recent educational tool under background music in preclinical endodontic training. Accordingly, Stress-VAS 2 and STAI-S values were significantly lower among students who listened to Mozart's music. Reduced stress and anxiety levels could have been observed due to the release of dopamine, which is the body's natural happy chemical that improves a person's mood and also blocks the release of stress (40).

According to the results, the higher target process and accuracy values were observed in the group where the background music was applied. Listening to calming and soothing music might have led to better focus and concentration, which could potentially benefit the student's performance during preclinical endodontic training (22). Furthermore, music may have acted as a distraction, positively affecting the student's motivation while performing challenging practices. Accordingly, the negative correlation between Stress-VAS 2 and dexterity levels in preclinical training also highlights the potential benefits of background music.

Although the Mozart effect theory has been shown to increase the success rate in applications (41), it is considered that the improving effect in preclinical education is indirect. It should be noted that the variable demographic characteristics and predispositions of the students may pose a risk of bias in the study results. Future studies are needed to comprehensively evaluate the effect of Mozart's music in preclinical endodontic training with different ethnic groups and larger numbers of participants.

Conclusion

Background Mozart's music had a positive effect on dexterity as well as students' stress and anxiety levels in preclinical endodontic training using an HVRS.

Authorship Contributions: Concept: S.N.U., E.D., Z.U.A.; Design: S.N.U., E.D., Z.U.A.; Supervision: S.N.U., Z.U.A.; Materials: S.N.U., E.D., Z.U.A.; Data: S.N.U., E.D.; Analysis: S.N.U.; Literature search: S.N.U., Z.U.A.; Writing: S.N.U., Z.U.A.; Critical revision: S.N.U., Z.U.A.

Use of AI for Writing Assistance: Not declared

Source of Funding: None declared.

Conflict of Interest: The authors declare that they have no competing interests.

Ethical Approval: This study was performed in line with the principles of the Declaration of Helsinki. The study protocol was approved by the Ethics Committee of the University where the study was conducted (No: 2023-37).

References

1. Roudsari MS, Namdari M, Mortazavi H, et al. Psychosocial impacts, perceived stress, and learning effects during the transition from preclinical to clinical dental education: Validation and translation of a questionnaire. Dent Res J (Isfahan) 2022; 19: 26. [CrossRef]
2. Suvinen TI, Messer LB, Franco E. Clinical simulation in teaching preclinical dentistry. Eur J Dent Educ 1998; 2: 25–32. [CrossRef]
3. Alobaid AS, Cortes LM, Lo J, et al. Radiographic and clinical outcomes of the treatment of immature permanent teeth by revascularization or apexification: A pilot retrospective cohort study. J Endod 2014; 40: 1063–70. [CrossRef]
4. Alobaid MA, Bin Hassan SA, Alfarhan AH, et al. A Critical evaluation of the undergraduate endodontic teaching in dental colleges of Saudi Arabia. Int J Environ Res Public Health 2022;19: 15534. [CrossRef]
5. Bertoli E, Lawson KP, Bishop SS. Dental students' skills

assessments: Comparisons of daily clinical grades and clinical and laboratory assessments. J Dent Educ 2018; 82: 417–23. [CrossRef]
6. Sadeghi HS, Alsaffarini MW, Almahmeed NW, et al. The impact of reflex-based recreational activities and preclinical training on psychomotor skills in an educational dental environment. J Dent Educ 2023; 87: 374–84. [CrossRef]
7. Nassri MR, Carlik J, da Silva CR, et al. Critical analysis of artificial teeth for endodontic teaching. J Appl Oral Sci 2008; 16: 43–9. [CrossRef]
8. Robberecht L, Chai F, Dehurtevent M, et al. A novel anatomical ceramic root canal simulator for endodontic training. Eur J Dent Educ 2017; 21: e1–6. [CrossRef]
9. Al-Sudani DI, Basudan SO. Students' perceptions of preclinical endodontic training with artificial teeth compared to extracted human teeth. Eur J Dent Educ 2017; 21: e72–5. [CrossRef]
10. Aminoshariae A, Nosrat A, Nagendrababu V, et al. Artificial intelligence in endodontic education. J Endod 2024; 50: 562–78. [CrossRef]
11. Suebnukarn S, Hataidechadusadee R, Suwannasri N, et al. Access cavity preparation training using haptic virtual reality and microcomputed tomography tooth models. Int Endod J 2011; 44: 983–9. [CrossRef]
12. Hsu MH, Liu CM, Chen CJ, et al. Virtual 3D tooth creation for personized haptic simulation training in access cavity preparation. J Dent Sci 2022; 17: 1850–3. [CrossRef]
13. Farag A, Hashem D. Impact of the haptic virtual reality simulator on dental students' psychomotor skills in preclinical operative dentistry. Clin Pract 2021; 12: 17–26. [CrossRef]
14. Suebnukarn S, Chaisombat M, Kongpunwijit T, et al. Construct validity and expert benchmarking of the haptic virtual reality dental simulator. J Dent Educ 2014; 78: 1442–50. [CrossRef]
15. Rodrigues P, Nicolau F, Norte M, et al. Preclinical dental students self-assessment of an improved operative dentistry virtual reality simulator with haptic feedback. Sci Rep 2023; 13: 2823. [CrossRef]
16. Mirza MB. Difficulties encountered during transition from preclinical to clinical endodontics among Salman bin Abdul Aziz University Dental Students. J Int Oral Health 2015; 7: 22–7.
17. Divaris K, Mafla AC, Villa-Torres L, et al. Psychological distress and its correlates among dental students: A survey of 17 Colombian dental schools. BMC Med Educ 2013; 13: 91. [CrossRef]
18. Varma SR, Thomas S, Al Radaideh A, et al. The impact of background music in reducing stress during preclinical dental laboratories. J Int Soc Prev Community Dent 2019; 9: 77–82. [CrossRef]
19. George RP, Donald PM, Soe HHK, et al. Prevalence of symptoms of depression, anxiety, and stress among undergraduate dental students in Malaysia. J Contemp Dent Pract 2022; 23: 532–8. [CrossRef]
20. Di Nasso L, Nizzardo A, Pace R, et al. Influences of 432 Hz music on the perception of anxiety during endodontic treatment: A randomized controlled clinical trial. J Endod 2016; 42: 1338–43. [CrossRef]
21. Wazzan M, Estaitia M, Habrawi S, et al. The effect of music therapy in reducing dental anxiety and lowering physiological stressors. Acta Biomed 2022; 92: e2021393.
22. Mendes CG, Diniz LA, Marques Miranda D. Does music listening affect attention? A literature review. Dev Neuropsychol 2021; 46: 192–212. [CrossRef]
23. Jausovec N, Jausovec K, Gerlic I. The influence of Mozart's music on brain activity in the process of learning. Clin Neurophysiol 2006; 117: 2703–14. [CrossRef]
24. Felszeghy S, Liukkonen M, Tornero CS, et al. Influence of background music on stress reduction and impact on performances during students' simulation exercises. J Dent Educ 2023; 87: 1170–9. [CrossRef]
25. Kayaaltı-Yüksek S, Yıldırım S. Effect of Mozart's music on the learning of toothbrushing behavior in children with high and low dental anxiety levels. Clin Oral Investig 2022; 26: 5979–88. [CrossRef]
26. Chevalier V, Dessert M, Fouillen KJ, et al. Preclinical 3D-printed laboratory simulation of deep caries and the exposed pulp reduced student anxiety and stress, while increasing confidence and knowledge in vital pulp treatment. Int Endod J 2022; 55: 844–57. [CrossRef]
27. Lesage FX, Berjot S, Deschamps F. Clinical stress assessment using a visual analogue scale. Occup Med (Lond) 2012; 62: 600–5. [CrossRef]
28. Kishida M, Yamada Y, Inayama E, et al. Effectiveness of music therapy for alleviating pain during haemodialysis access cannulation for patients undergoing haemodialysis: A multi-facility, single-blind, randomised controlled trial. Trials 2019; 20: 631. [CrossRef]
29. Lee WL, Sung HC, Liu SH, et al. Meditative music listening to reduce state anxiety in patients during the uptake phase before positron emission tomography (PET) scans. Br J Radiol 2017; 90: 20160466. [CrossRef]
30. Virteasy Dental. Virteasy Dental brochure. Available at: https://virteasy.com/wp-content/uploads/2021/08/Virteasy_Dental_V2_Brochure-1.pdf. Accessed Jul 22, 2024.
31. Spielberger CD, Gorsuch RL, Lushene R, et al. Manual for the State-Trait Anxiety Inventory (Form Y1-Y2). Washington, DC: Consulting Psychologists Press; 1983.
32. Öner N, Le Compte A. Durumluk sürekli kaygı envanteri el kitabı. İstanbul: Boğaziçi Üniversitesi Yayınları; 1983.
33. Bitter K, Gruner D, Wolf O, Schwendicke F. Artificial versus natural teeth for preclinical endodontic training: A randomized controlled trial. J Endod 2016; 42: 1212–7.

[CrossRef]
34. Mocny-Pachońska K, Doniec R, Trzcionka A, et al. Evaluating the stress-response of dental students to the dental school environment. PeerJ 2020; 8: e8981. [CrossRef]
35. Thoma MV, La Marca R, Brönnimann R, et al. The effect of music on the human stress response. PLoS One 2013; 8: e70156. [CrossRef]
36. Martins JNR, Marques D, Mata A, et al. Root and root canal morphology of the permanent dentition in a Caucasian population: A cone-beam computed tomography study. Int Endod J 2017; 50: 1013–26. [CrossRef]
37. Packyanathan JS, Lakshmanan R, Jayashri P. Effect of music therapy on anxiety levels on patient undergoing dental extractions. J Family Med Prim Care 2019; 8: 3854–60. [CrossRef]
38. Fu VX, Oomens P, Merkus N, et al. The perception and attitude toward noise and music in the operating room: A systematic review. J Surg Res 2021; 263: 193–206. [CrossRef]
39. Lee JI. Dental education now and in the future. J Periodontal Implant Sci 2023; 53: 171–2. [CrossRef]
40. Moraes MM, Rabelo PCR, Pinto VA, et al. Auditory stimulation by exposure to melodic music increases dopamine and serotonin activities in rat forebrain areas linked to reward and motor control. Neurosci Lett 2018; 673: 73–8. [CrossRef]
41. Rauscher FH, Shaw GL, Ky KN. Music and spatial task performance. Nature. 1993; 365: 611. [CrossRef]

ORIGINAL ARTICLE

Turk Endod J 2024;9(2):103–110
doi: 10.14744/TEJ.2024.38258

A topographic analysis of the surface changes in reciprocating and rotary Ni-Ti instruments after multiple uses

Gülsen Kiraz, Arzu Kaya Mumcu, Safa Kurnaz

Department of Endodontics, Faculty of Dentistry, Kutahya Health Sciences University, Kütahya, Türkiye

Purpose: This study aims to investigate the impact of repeated use within curved root canals on the surface characteristics of both reciprocating and rotary instruments, using Field Emission Scanning Electron Microscopy (FESEM) for detailed analysis.

Methods: Curved acrylic blocks were randomly divided into two groups and were prepared using WaveOne Gold (WOG) and One Curve (OC) files. Both WOG and OC groups were further divided into subgroups: control, 1st use, 2nd use, 3rd use, and separated files. Following each use, the instruments underwent ultrasonic cleaning and sterilization procedures. These procedures continued until fracture occurred and changes in the surface characteristics of files were examined under FESEM. Descriptive data were reported for each group.

Results: With increasing use within each group, the instruments exhibited a rise in the frequency of surface damage, including cracks, flattening, deterioration of cutting edges, microcavities, and debris accumulation. A fracture occurred in the OC file after the 8th use, while the WOG file fractured after the 6th use.

Conclusion: Repeated use increased defects and deformations in both files. Based on the surface characteristics of both files, single-use applications of WOG and OC files are considered safer.

Keywords: Field emission scanning electron microscopy; One Curve; separated file; topographic change; WaveOne Gold.

Introduction

Nickel-titanium (Ni-Ti) instruments have revolutionized endodontics due to their high flexibility, enhanced cyclic fatigue resistance, and superior torsional strength (1). These properties facilitate efficient root canal preparation, reduce operator fatigue, shorten procedure times, and enable the safe preparation of curved anatomies (1). However, despite their widespread adoption, Ni-Ti files are not without limitations. The most concerning complication associated with their use is instrument separation within the root canal. This separation can arise from flexural fatigue, torsional fatigue, or a combination of these mechanisms (2).

Although instrument fractures within the root canal system do not invariably compromise treatment success, their presence undeniably impedes effective microbial control and introduces complexities into the endodontic treatment process (3). Moreover, retrieving a separated file may lead to excessive dentin removal, compromised root

Cite this article as: Kiraz G, Kaya Mumcu A, Kurnaz S. A topographic analysis of the surface changes in reciprocating and rotary Ni-Ti instruments after multiple uses. Turk Endod J 2024;9:103-110.
Correspondence: Gülsen Kiraz. Kutahya Health Sciences University, Kütahya, Türkiye
Tel: +90 275 – 260 00 43 e-mail: gulsen.kiraz@ksbu.edu.tr
Submitted: March 19, 2024 Revised: June 03, 2024 Accepted: June 25, 2024 Published: August 29, 2024

strength, and perforation. These frustrating complications can occur even in skilled hands (4).

Novel production strategies that leverage diversified thermomechanical processes are emerging to enhance Ni-Ti instrument mechanics, minimize fracture risk, and prolong lifespan. Thermomechanical processes induce phase transformations within the Ni-Ti alloy (5). Ni-Ti files exhibit three distinct microstructural phases: austenite (rigid), martensite (flexible), and R-phase (intermediate). The amount of alloy in each phase affects the mechanical properties of the file (6). Conventional Ni-Ti files have an austenite structure, and depending on the austenite finish (Af) temperature, direct phase transformation from austenite to martensite can occur in a single stage (7). Manipulating Af temperatures via post-heat treatment is conducted with the aim of altering the alloy's phase ratios and thereby enhancing flexibility and cyclic fatigue resistance to obtain safer, more durable instruments (8).

These new production strategies have led to the emergence of alloys such as M-wire, gold-wire, and C-wire (9). The WaveOne Gold system (WOG; Dentsply Sirona, Ballaigues, Switzerland) is a reciprocal system that is manufactured from a gold-wire and exhibits high flexibility, resistance to cyclic fatigue, and effective cutting. Gold heat treatment is carried out by heating the instrument and then slowly cooling it (10). This system consists of four file pieces: #20.07 (small), #25.07 (primary), #35.06 (medium), and #45.05 (large) (10). The unique parallelogram shape and two cutting edges of these files help minimize contact with canal walls while effectively clearing debris (10).

Micro-Mega has developed the One Curve (OC; Micro Mega, Besancon, France) rotational single-file system from C-Wire using a new heat treatment process. This special heat treatment imbues the files with remarkable pre-bending flexibility and controlled memory properties, ensuring the faithful preservation of the original root canal shape (11). This system consists of four file pieces (#20.04, #25.06, #35.04, and #45.04) with a variable cross-section design (triple helical cross-section at the tip and S-shaped cross-section close to the handle). In addition, the electropolishing process ensures that its resistance to cyclic fatigue is high, and the C-wire technology reduces the attachment of the instrument to inclined root canal walls, which facilitates root canal preparation (12).

There is no consensus in the literature about how many times a Ni-Ti instrument can be used safely in root canals and whether there is a difference in the amount of topographic change that occurs in the files when rotational and reciprocal file systems are used, especially in curved root canals. Therefore, the aim of this study was to examine the topographic changes that occur on file surfaces before and after single and multiple uses of single-file systems operating with reciprocal and rotational movements in curved root canals, using field emission scanning electron microscopy (FESEM).

The following null hypotheses were tested in this study:

1. There will be no differences in the topographic changes exhibited by WOG and OC files before preparation and after multiple uses.

2. There will be no difference in instrument separation between WOG and OC files based on the number of uses.

Materials and Methods

Sample Selection and Groups

The manuscript of this laboratory study has been written according to Preferred Reporting Items for Laboratory Studies in Endodontology (PRILE) 2021 guidelines.

As this study involved in vitro experiments, ethical committee approval was not required. A total of 14 simulated single root canals (EduDent, EndoPrep, İstanbul, Turkey), with a length of 16 mm, curvature radius of 3 mm, and curvature of 30°, were used for root canal preparation. Acrylic blocks were randomly divided into two groups—one group was prepared using WOG instruments and the other with OC instruments. Both WOG and OC files were divided into five subgroups: control, first use, second use, third use, and separated files.

Preparation of Root Canals

WOG Group (n = 5): WOG Glider (#15.02) and WOG Primary (#25.07) files were used with an X-Smart Plus motor (Dentsply Maillefer) in the WaveOne ALL mode, following the manufacturer's instructions and applying light apical pressure. Up-and-down movements of 3 mm were performed three times, followed by file removal, cleaning, and irrigation with 2 mL of 2.5% NaOCl. This cycle was repeated until the working length (WL) was reached. After each use, the files were removed, ultrasonic bath and sterilization procedures were applied, and then FESEM examinations were performed. On the second simulated tooth, the same WOG files and processes were used again. The same procedures were repeated on the third simulated tooth until a separated file occurred. To evaluate the metallurgical changes, the separated file piece was taken and observed via FESEM (Fig. 1).

OC Group (n = 5): One G (Micro Mega, Besancon, France) and OC 25.06 files (Micro Mega, Besancon, France) were used with the same motor, a light apical pressure, and a continuous rotational movement at 300 rpm speed and 2.5 N/cm torque, in accordance with the manu-

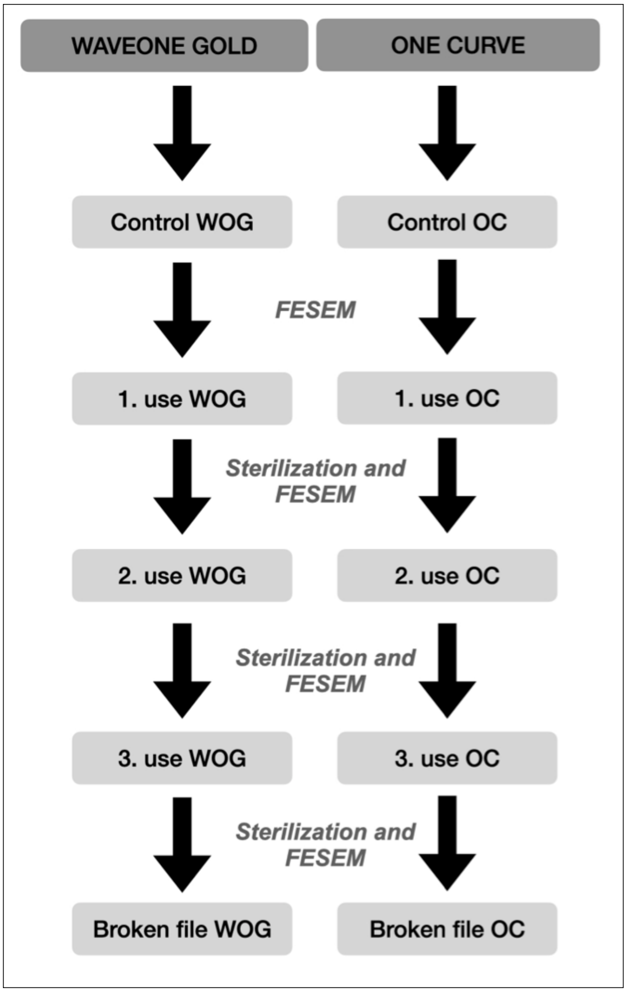


Fig. 1. Group distribution.

facturer's instructions. After every three strokes, the files were withdrawn and cleaned, followed by thorough irrigation with 2 mL of 2.5% NaOCl. After each use of the files, ultrasonic bath and sterilization procedures were applied, and then FESEM examinations were performed. On the second simulated tooth, the same OC files and processes were applied again. These procedures were repeated on the third simulated tooth until a fracture occurred. To evaluate the metallurgical changes, the separated file piece was observed via FESEM (Fig. 1).

Sterilization Procedures

The files were placed in an ultrasonic bath (Mercury, İstanbul, Türkiye) containing a precleaning enzymatic solution (Clenesafe PRO-ENZYM, Ruson Chemistry, İstanbul, Turkey) for 15 minutes. The instruments were then placed on sterilization papers that included information about the group and number of uses and were sterilized in an autoclave (Sümer, Ankara, Türkiye) for 30 minutes at 121°C and 210 KPa. This sterilization procedure was repeated after the files were used in each root canal.

FESEM Observations

Ni-Ti instruments were mounted and fixed in a standard position, and the surface properties of the files were analyzed using FESEM (Hitachi Regulus 8230, Co., Tokyo, Japan) at x100, x500, x2000, and x10000 magnifications. Photomicrographs of the 3 mm apical parts of the control files and the used files (WOG1, WOG2, WOG3, WOG separated file, OC1, OC2, OC3, and OC separated file) were compared and evaluated according to the following criteria: microcracks, debris, flattening of the file surface, deterioration of the cutting edge/blunting, and microcavity and burr amounts. During the evaluations, Troian et al.'s (12) three-point scoring system for spiral deterioration and four-point scoring system for surface wear were used (Table 1). All resulting micrographs were analyzed blindly using two precalibrated observers (0.89 kappa test). Descriptive data were reported for each group.

Results

The topographic changes of the files in the groups were examined, and the following results were obtained.

WOG Group

First Use: Examination of the file surfaces revealed no evidence of cracking or flattening. However, deterioration/blunting of the cutting edges, microcavities, and the presence of debris and burrs were observed (Fig. 2).

Second and Third Uses: Similar topographic changes were observed after the second and third uses of the WOG files,

Table 1. Scores for the spiral deterioration and surface wear of the files

Score	Spiral deterioration	Surface wear
1	No unraveling or reverse spiraling of the spirals	No deterioration along the surface
2	Unraveling and reverse spiraling observed in only one spiral	Minor deterioration present: 1-3 areas of defects along the surface
3	Unraveling and reverse spiraling observed in more than one spiral	Moderate amount of deterioration: 4-5 defective areas along the surface
4	–	Severe deterioration: more than 5 defective areas

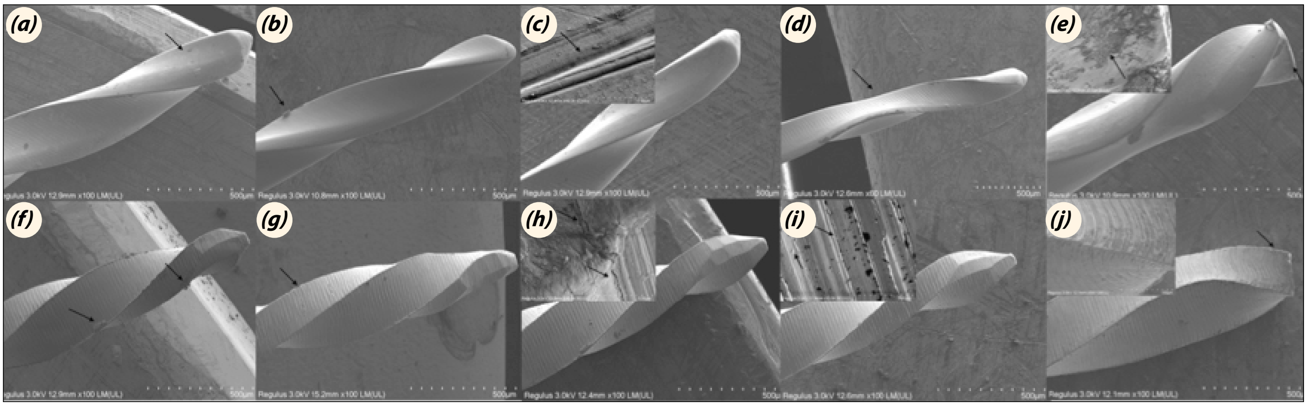


Fig. 2. Representative FESEM micrographs of the OC file surfaces **(a)** The arrow showing the presence of microcavities on the surface of the OC control file **(b)** The arrow showing the presence of burs on the surface of the OC first use file **(c)** The arrow showing the presence of microcrack on the surface of the OC second use file **(d)** The arrow showing the presence of flattening the surface of the OC third use file. **(e)** The arrows showing the presence of pitting corrosion the surface of the OC separated file. Representative FESEM micrographs of the WOG file surfaces **(f)** The arrows showing the presence of burs on the surface of the WOG control file **(g)** The arrow showing the presence of deterioration on the cutting edge of the WOG first use file **(h)** The arrow showing the presence of microcrack on the surface of the WOG second use file **(i)** The arrow showing the presence of debris and microcrack the surface of the WOG third use file **(j)** The arrows showing the presence of deterioration of the cutting edge of the WOG separated file.

with an increase in the number of cracks and debris on the file surfaces and deterioration/blunting of the cutting edge. However, there was no change in the microcavity and burr amount compared to the first use (Fig. 2).

Sixth Use and Fracture: It was found that by the sixth use, the cracks had spread over a large area, causing the files to break. Morphological examinations of the separated parts revealed the presence of pitting corrosion in significant areas. An increased amount of file flattening was observed, and deterioration/blunting on the cutting edge increased in proportion to the number of uses (Fig. 2).

OC Group

First Use: Examination of the file surfaces revealed no evidence of cracking, flattening, or deterioration/blunting of the cutting edges. However, microcavities, debris, and burrs were observed (Fig. 2).

Second Use: An increase in the number of cracks and debris on the file surfaces and deterioration and blunting of the cutting edge were observed. However, there was no change in the microcavity and burr amount compared to the first use (Fig. 2).

Third Use: An increased number of cracks on the file surfaces and further deterioration of the cutting edge were observed. Additionally, file flattening was observed for the first time after the third use. A difference in the amount of debris, microcavities, and burrs was observed compared to the second use (Fig. 2).

Eighth Use and Fracture: An examination of the separated file surfaces showed that the cracks had spread over a large area, causing the files to break. Morphological examinations of the separated parts revealed pitting corrosion in large areas. An increased amount of file flattening was observed. The deterioration/blunting of the cutting edge increased in proportion to the number of uses (Fig. 2).

The FESEM images revealed a greater accumulation of debris on the files that ultimately fractured in both groups, as compared to their less-used counterparts. The OC files fractured within the acrylic blocks on their eighth use, while the WOG files fractured upon their sixth use.

Discussion

The changes in the surface characteristics of reciprocal and rotary instruments following their repeated use in curved root canals, as well as the topographic changes in separated instruments, were investigated in this study. The results revealed that as the number of uses increased in both groups, cracks, flattening, deterioration of cutting edges, and microcavities on the file surfaces, debris, and smearing increased in frequency. Additionally, morphological examinations of the cross-sections of the separated pieces revealed pitting corrosion in wide areas. Therefore, the null hypotheses were rejected.

Ledesma-Montes et al. (13) reported the frequency of root dilaceration as 54.4% in the maxillary teeth and 45.6% in the mandibular teeth. Curved root canals, in particular, have so far created many difficulties for dentists and endodontists during root canal treatment. In curved root canals, the incidence of procedural errors such as apical transportations, root perforations, deterioration/blunting of files, and instrument separation are higher during root canal preparation compared to straight root canals (14,15). This study adopted a similar methodology to previous investigations (16-18) by employing moderately curved (30°) simulated acrylic root canals based on the Schneider method (19) for curvature calculation.

Several studies that have used scanning electron microscopy (SEM) to evaluate changes in the morphological characteristics of metallic materials have reported that SEM is a suitable method for accurately evaluating the deformation of files (12,20,21). FESEM is similar to traditional SEM but uses electrons instead of photons. In addition, unlike conventional SEM, FESEM does not require the sample to be metalized and enables detailed examination of the topography of the sample surface. Therefore, in this study, FESEM was used to evaluate the deformations and changes in the morphological characteristics of the instrument's surface.

The presence of a separated endodontic instrument within a root canal system has a negative prognostic effect on orthograde endodontic treatment, as it prevents the cleaning and shaping of the apical root canal (3). Instrument fracture, a complication of cyclic fatigue and torsional stress, especially in severely curved root canals, persists despite advancements in design, alloys, manufacturing, and techniques. This fracture can occur abruptly and unpredictably (22). The incidence of instrument fracture varies between 0.4% and 23% (3). It has been reported that 66–78% of these occurrences are due to cyclic fatigue, and 91% are due to torsional fatigue (23). In the present study, two instruments with different cross-sectional designs, heat treatments, and kinematics were compared. A WOG file is a reciprocating single file system with a parallelogram cross-section, two cutting edges, and an off-center design. Additionally, this file system has a gold heat treatment that occurs by heating and cooling slowly before manufacturing, thus increasing the elasticity of the file (24). An OC file is also a single rotation file system with a heat-treated C-wire, a triple helical cross-section in the apical part, and an S-shaped cross-section in the middle and coronal parts. Therefore, instruments with the same tip diameter (#25) and similar tapers were selected to minimize the study variables, as it is challenging to compare different instruments that vary in their heat treatments, kinematics, and design features. Previous studies have reported that the single-file technique results in significantly short preparation times compared to other full-sequence systems (25). Additionally, the experience levels of clinicians may also impact the deformation and fracture of the instruments used (26). Therefore, in this study, a single-file system was preferred, and an experienced endodontist performed the instrumentation.

Some topographic changes were observed on the surfaces of the files when they were evaluated after each use. Before use, there were some debris, burrs, and microcavities on the surfaces of the OC files, whereas there were no debris or microcavities on the surfaces of the WOG files. Karamifar et al. (20) and Saghiri et al. (27) reported the presence of pre-existing debris on the instruments utilized in their investigations. The authors stated that this could have been due to pre-use contamination and the manufacturing stages of the files. However, Pirani et al. (21) did not observe any such debris accumulation before use. The literature lacks a definitive consensus regarding pre-existing debris on instruments. The reported discrepancies might be attributable to variations within the manufacturing processes employed by different companies. As the number of uses increases, small surface deformations on the files can lead to further surface deformation and increased debris accumulation in these areas. Previous studies have reported that this situation may be caused by a reaction between the file surface and the irrigation solution (NaOCl), the electrostatic bond between the metal and the debris, or debris settling into microcracks (28), which may explain the topographic changes seen in our study.

Manufacturing processes of Ni-Ti files may result in uneven surfaces characterized by irregular edges, grooves, burrs, and microcavities. Hannan et al. (29) reported that microcavities on file surfaces distribute stress and may cause deterioration or flattening of cutting edges where stress is concentrated. In this study, crack formation and flattening of the file surfaces were not observed after the first use. However, deterioration/blunting of the cutting edges was observed after the second use of the OC files and after the first use of the WOG files. This finding confirms that microcavities on the file surfaces during the production phase affect the deterioration or blunting of the cutting edge, which increases with the number of uses.

Ni-Ti files may break during clinical use as a result of cyclic or torsional fatigue (30). Torsional fatigue failure occurs when the tip of the instrument gets stuck at any point in the canal and the stress caused by the continued rotation of the shaft exceeds the elasticity limit of the instrument. Cyclic fatigue fracture is caused by the accumulation of repetitive tensile and compressive stresses on a file subjected to curved canals. Cyclic fatigue has been reported as the main cause of instrument fractures during clinical use (30). In this study, fracture was observed on the eighth use of the OC files and the sixth use of the WOG files. Cyclic fatigue is affected by an instrument's kinematics, alloy, and metallurgical properties (31). Studies have reported that continuous rotational movement causes both tensile and compressive stresses in the inclined area and thus results in more cyclic fractures than reciprocation movement (32,33). However, in this study, the cyclic fracture resistance of the OC files, which involved continuous rotary motions, was found to be higher than that of the WOG files. Previous studies have suggested that reducing the core area may increase the fracture resistance of an instrument (34). Compared to tools with parallelogram cross-sections, tools with S-shaped cross-sections have lower core areas and thus exhibit better resistance to cyclic fatigue (34). The S-shaped cross-section of OC files may be a reason for their high resistance to cyclic fatigue. Compared to the WOG files, the OC files in this study separated more with use, which may have been due to the aforementioned reason.

The cyclic fatigue resistance of the OC files in this study may be partially attributed to the martensitic phase at room and intracanal temperatures. Previous studies have shown that modifying Ni-Ti instrument phases by adjusting the austenite start (As) and Af temperatures influences fatigue resistance (6,35). Stafoli et al. (35) reported that OC files' Af is between 40°C and 50°C, and they remain martensitic throughout their use, potentially contributing to superior fatigue performance compared to austenitic files, which are known for their relatively low flexibility and fatigue resistance (36).

Manufacturers recommend that Ni-Ti files should be used only once due to the wear and deformations caused on their surfaces by root canal preparation, irrigation solutions, and sterilization–disinfection processes (37). Pirani et al. (21) demonstrated through an energy dispersive X-ray spectroscopy (EDS) analysis that dentin residues accumulate in the grooves of these files, and they recommended the use of single-use endodontic instruments to reduce the possibility of cross-contamination. However, in clinical conditions, files may be used more than once for up to 3–4 root canals in the same molar or the same patient (21). Therefore, the cleaning, disinfection, and sterilization process is very important for minimizing and preventing the risk of cross-infection (21). In this study, the files underwent ultrasonic cleaning to eliminate any biological debris before autoclave sterilization.

A limitation of this study is that it was conducted using simulated root canals. Acrylic blocks simulate canals with highly standardized shapes, sizes, tapers, and curvatures. This provides a standard in vitro condition for comparing instrumentation techniques and devices (38). Acrylic blocks were used in this study to standardize and fix these factors; however, the mechanical properties of acrylic blocks differ from those of human dentin. The heat produced during instrumentation may soften acrylic, causing it to grip the cutting blades of the instruments, and due to the circular cross-section of the simulated canals, the findings obtained cannot be directly applied to clinical practice (38). However, the findings provide information on the fracture resistance of the instruments and the changes in surface properties that occur depending on the number of uses. Another limitation of our study is that only one type of rotary file and one type of reciprocating file were selected. Therefore, the results of this study cannot be generalized to all rotary and reciprocating systems.

Conclusion

In the present study, the OC files showed better fracture resistance than the WOG files. The results of this study showed that defects and deformations increased in both file types as the number of uses increased. The fracture resistance of Ni-Ti instruments is affected by their cross-sectional design, alloy properties, and heat treatments. Therefore, considering the evaluation of the surface properties of these files, a single use of WOG and OC files is safer than repeated use. Increasing the number of uses causes changes in the file surfaces, which increases the risk of fractures and negatively affects the prognosis of the treatment.

*This study will be presented as an oral presentation at 30th Izmir Chamber of Dentists International Scientific Congress and Exhibition on November 24-26, 2023 in İzmir, Turkey.

Authorship Contributions: Concept: G.K., A.K.M.; Design: G.K., A.K.M., S.K.; Supervision: Ö G.K., A.K.M., S.K.; Materials: G.K., A.K.M., S.K.; Data: G.K., A.K.M.; Analysis: S.K.; Literature search: G.K., A.K.M.; Writing: G.K., A.K.M., S.K.; Critical revision: G.K., A.K.M., S.K.

Acknowledgements: The authors deny any conflicts of interest related to this study.

Use of AI for Writing Assistance: Not declared

Source of Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest: The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

References

1. Pedullà E, Lo Savio F, Boninelli S, et al. Torsional and cyclic fatigue resistance of a new nickel-titanium instrument manufactured by electrical discharge machining. J Endod 2016; 42: 156–9. [CrossRef]
2. Wei X, Ling J, Jiang J, et al. Modes of failure of ProTaper nickel-titanium rotary instruments after clinical use. J En-

dod 2007; 33: 276–9. [CrossRef]
3. Spili P, Parashos P, Messer HH. The impact of instrument fracture on outcome of endodontic treatment. J Endod 2005; 31: 845–50. [CrossRef]
4. Souter NJ, Messer HH. Complications associated with fractured file removal using an ultrasonic technique. J Endod 2005; 31: 450–2. [CrossRef]
5. Shen Y, Zhou HM, Zheng YF, et al. Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments. J Endod 2013; 39: 163–72. [CrossRef]
6. Pereira ÉS, Viana AC, Buono VT, et al. Behavior of nickel-titanium instruments manufactured with different thermal treatments. J Endod 2015; 41: 67–71. [CrossRef]
7. Alapati SB, Brantley WA, Iijima M, et al. Metallurgical characterization of a new nickel-titanium wire for rotary endodontic instruments. J Endod 2009; 35: 1589–93. [CrossRef]
8. Hieawy A, Haapasalo M, Zhou H, et al. Phase transformation behavior and resistance to bending and cyclic fatigue of protaper gold and protaper universal instruments. J Endod. 2015; 41: 1134–8. [CrossRef]
9. Capar ID, Ertas H, Arslan H. Comparison of cyclic fatigue resistance of novel nickel-titanium rotary instruments. Aust Endod J 2015; 41: 24–8. [CrossRef]
10. Adıgüzel M, Capar ID. Comparison of cyclic fatigue resistance of waveone and waveone gold small, primary, and large instruments. J Endod 2017; 43: 623–7. [CrossRef]
11. Elnaghy AM, Elsaka SE. Cyclic fatigue resistance of One Curve, 2Shape, ProFile Vortex, Vortex Blue, and RaCe Nickel-Titanium Rotary instruments in single and double curvature canals. J Endod 2018; 44: 1725–30. [CrossRef]
12. Troian CH, Só MV, Figueiredo JA, et al. Deformation and fracture of RaCe and K3 endodontic instruments according to the number of uses. Int Endod J 2006; 39: 616–25. [CrossRef]
13. Ledesma-Montes C, Jiménez-Farfán MD, Hernández-Guerrero JC. Dental developmental alterations in patients with dilacerated teeth. Med Oral Patol Oral Cir Bucal 2019; 24: e8–11. [CrossRef]
14. Estrela C, Pécora JD, Estrela CRA, et al. Common operative procedural errors and clinical factors associated with root canal treatment. Braz Dent J 2017; 28: 179–90. [CrossRef]
15. Liu Y, Chen M, Tang W, et al. Comparison of five single-file systems in the preparation of severely curved root canals: An ex vivo study. BMC Oral Health 2022; 22: 649. [CrossRef]
16. Bastos MMB, Hanan ARA, Bastos AMB, et al. Topographic and chemical analysis of reciprocating and rotary instruments surface after continuous use. Braz Dent J 2017; 28: 461–6. [CrossRef]
17. Almazedi RAK, Al-Zaka IM. Influence of two kinematics on canal transportation and centering ability of WaveOne Gold and One Curve files. Aust Endod J 2024; 50: 24–39. [CrossRef]
18. El Abed R, Alshehhi A, Kang YJ, et al. Fracture resistance of heat-treated nickel-titanium rotary files after usage and autoclave sterilization: An in vitro study. J Endod 2022; 48: 1428–33. [CrossRef]
19. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol 1971; 32: 271–5. [CrossRef]
20. Karamifar K, Samavi S, Saghiri MA. Topographic changes in NiTi rotary instruments after the clinical use. Aust Endod J 2020; 46: 315–22. [CrossRef]
21. Pirani C, Paolucci A, Ruggeri O, et al. Wear and metallographic analysis of WaveOne and reciproc NiTi instruments before and after three uses in root canals. Scanning 2014; 36: 517–25. [CrossRef]
22. Cheung GS, Peng B, Bian Z, et al. Defects in ProTaper S1 instruments after clinical use: fractographic examination. Int Endod J 2005; 38: 802–9. [CrossRef]
23. Shen Y, Coil JM, Haapasalo M. Defects in nickel-titanium instruments after clinical use. Part 3: A 4-year retrospective study from an undergraduate clinic. J Endod 2009; 35: 193–6. [CrossRef]
24. Webber J. Shaping canals with confidence: WaveOne GOLD single-file reciprocating system. Roots 2015; 1: 34–40.
25. Paqué F, Zehnder M, De-Deus G. Microtomography-based comparison of reciprocating single-file F2 ProTaper technique versus rotary full sequence. J Endod 2011; 37: 1394–7. [CrossRef]
26. Yared GM, Bou Dagher FE, Machtou P. Influence of rotational speed, torque and operator's proficiency on ProFile failures. Int Endod J 2001; 34: 47–53. [CrossRef]
27. Saghiri MA, Karamifar K, Mehrvazfar P, et al. The efficacy of foam cleaners in removing debris from two endodontic instruments. Quintessence Int 2012; 43: 811–7.
28. Kottoor J, Velmurugan N, Gopikrishna V, et al. Effects of multiple root canal usage on the surface topography and fracture of two different Ni-Ti rotary file systems. Indian J Dent Res 2013; 24: 42–7. [CrossRef]
29. Hanan AR, Meireles DA, Sponchiado Júnior EC, et al. Surface characteristics of reciprocating instruments before and after use - A SEM analysis. Braz Dent J 2015; 26: 121–7. [CrossRef]
30. Shen Y, Cheung GS, Bian Z, et al. Comparison of defects in ProFile and ProTaper systems after clinical use. J Endod 2006; 32: 61–5. [CrossRef]
31. Kitchens GG Jr, Liewehr FR, Moon PC. The effect of operational speed on the fracture of nickel-titanium rotary instruments. J Endod 2007; 33: 52–4. [CrossRef]
32. Thu M, Ebihara A, Maki K, et al. Cyclic fatigue resistance of rotary and reciprocating nickel-titanium instruments

subjected to static and dynamic tests. J Endod 2020; 46: 1752–7. [CrossRef]

33. De-Deus G, Moreira EJ, Lopes HP, et al. Extended cyclic fatigue life of F2 ProTaper instruments used in reciprocating movement. Int Endod J 2010; 43: 1063–8. [CrossRef]
34. Plotino G, Grande NM, Testarelli L, et al. Cyclic fatigue of Reciproc and WaveOne reciprocating instruments. Int Endod J 2012; 45: 614–8. [CrossRef]
35. Staffoli S, Grande NM, Plotino G, et al. Influence of environmental temperature, heat-treatment and design on the cyclic fatigue resistance of three generations of a single-file nickel-titanium rotary instrument. Odontology 2019; 107: 301–7. [CrossRef]
36. Zupanc J, Vahdat-Pajouh N, Schäfer E. New thermomechanically treated NiTi alloys - A review. Int Endod J 2018; 51: 1088–103. [CrossRef]
37. Yamazaki-Arasaki A, Cabrales R, Santos Md, et al. Topography of four different endodontic rotary systems, before and after being used for the 12th time. Microsc Res Tech 2012; 75: 97–102. [CrossRef]
38. Peters OA, Barbakow F. Dynamic torque and apical forces of ProFile.04 rotary instruments during preparation of curved canals. Int Endod J 2002; 35: 379–89. [CrossRef]

ORIGINAL ARTICLE

Turk Endod J 2024;9(2):111–118
doi: 10.14744/TEJ.2024.38257

The comparative evaluation of temperature changes on the external root surface during the application of different obturation techniques

Fatoş Albayrak, Recai Zan

Department of Endodontics, Faculty of Dentistry, Sivas Cumhuriyet University, Sivas, Türkiye

Purpose: The present research aimed to examine the possibility of damage to tooth support tissues induced by temperature changes on the external root surface while applying different obturation techniques.

Methods: One hundred fifty mandibular premolar teeth were prepared using a ProTaper Next nickel-titanium rotary file system. After the preparation, the distance between the inner dentin and the external cementum was measured at nine points with cone-beam computed tomography. Then, 100 teeth with the closest dentin thickness were included in the study. The teeth were randomly divided into five groups: cold lateral condensation, warm vertical condensation, continuous-wave obturation, thermoplastic injection, and carrier-based obturation techniques. Temperature changes were measured from the external root surface with the degree of intraoral temperature while applying obturation techniques.

Results: The warm vertical condensation technique caused the highest temperature increases statistically, and the lowest temperature increases were detected while applying the cold lateral condensation and carrier-based obturation techniques.

Conclusion: Consequently, obturation techniques may be safely preferred in terms of temperature increases that may cause damage to supporting tissues.

Keywords: Cone-beam computed tomography; dentin thickness; obturation techniques; temperature increases; warm gutta-percha.

Introduction

Endodontic treatment first aims to completely disinfect the root canal system from infected and necrotic tissue remnants and obturate it hermetically with a stable and biocompatible filling material that prevents microorganism migration (1,2).

The root canal system has a complex structure characterized by irregular dentin canals, accessory canals, transverse anastomoses, and apical deltas. Such a complex structure makes it difficult to obtain an impermeable root canal filling by chemomechanical preparation and subsequent root canal filling techniques (1,3). In this regard, it has been reported that approximately 58% of failures in endodontic

Cite this article as: Albayrak F, Zan R. The comparative evaluation of temperature changes on the external root surface during the application of different obturation techniques. Turk Endod J 2024;9:111-118.
Correspondence: Fatoş Albayrak. Sivas Cumhuriyet University, Sivas, Türkiye
Tel: +90 346 – 219 10 10 e-mail: fcotur@cumhuriyet.edu.tr
Submitted: January 01, 2024 Revised: May 30, 2024 Accepted: June 02, 2024 Published: August 29, 2024

treatment are caused by the inability to fill the root canal system in an ideally homogeneous way (4).

Various techniques have been tried to achieve a three-dimensional hermetic root canal filling. Nowadays, the cold lateral condensation technique is preferred the most among conventional root canal filling techniques (5,6). Controlled obturation of gutta-percha while maintaining shape integrity is an important advantage of the aforesaid technique. However, it has been stated that the gutta-percha used in this technique has disadvantages, such as insufficient adaptation to root canal irregularities, the inability to adequately fill accessory canals, and the formation of gaps that may cause leakage during root canal filling (3,7-10). Therefore, new techniques that ensure hermetic filling of root canals with thermoplastic gutta-percha have been developed (11,12).

However, it should be remembered that these techniques, which provide numerous advantages in the success of root canal treatment, may also have some undesirable negative consequences during application. Possible temperature changes along the root canal walls during obturation are among the most important points regarding the safe application of obturation techniques with warm gutta-percha filling techniques.

It has been reported that warm gutta-percha root canal filling techniques may cause tissue damage due to the transfer to the periodontal tissues and alveolar bone (13). It is accepted that a 10 °C temperature increase above normal body temperature may cause irreversible damage to the tooth support tissues (14). A study revealed that a temperature of 56 °C causes the denaturation of alkaline phosphatases and leads to the onset of bone damage (15).

In light of this information, it is known that the temperature changes revealed while applying the warm gutta-percha technique are critical for the long-term success of endodontic treatment. The present research aimed to investigate the temperature changes measured while applying obturation techniques with thermocouples fixed to the external root surface. The hypothesis is that temperature changes on the external surface of the root during the application of different obturation techniques would not have a damaging effect on periodontal tissues.

Materials and Methods

Sivas Cumhuriyet University Non-Interventional Research Ethics Committee approved this study with the decision numbered 2019-09/07 at the meeting held on 11.09.2019. In the current research, mandibular premolar human teeth with a single root and a single canal were used. Tooth extraction was performed due to periodontal disease, orthodontic, or prosthetic treatment planning. Periapical radiographs of 150 extracted teeth in the mesiodistal and buccolingual directions were taken. Roots with resorption, cracks, or open apices were excluded from the study.

Tooth crowns were removed with a diamond fissure bur (Diatech Dental AG, Heerbrugg, Switzerland) under water cooling with a root length of approximately 14-16 mm to ensure working length standardization. The working length was determined by retracting 1 mm from the distance at which the #10 K-file was seen from the apical foramen. The teeth were prepared with a ProTaper Next nickel-titanium (PTN, Dentsply Maillefer, Ballaigues, Switzerland) rotary file system. 2 ml of 5.25% NaOCl (Imicryl Dental, Konya, Turkey) was utilized at every file change during root canal preparation, whereas 10 ml of 17% EDTA (Imicryl Dental, Konya, Turkey) was utilized when the preparation was complete and followed by 10 ml of 2.5% NaOCl. As final irrigation, the root canals were irrigated with 10 ml of distilled water and dried with paper points.

After the chemomechanical preparation, a standard silicon mold was prepared for evaluating dental cone-beam computer tomography (CBCT) (Rayscan Alpha, 12F, 221, Pangyoyeok-ro, Bunag-gu, Seongnam-si, Gyeonggi-do, Korea 13494). The teeth were embedded in the mold with the crowns up.

The tomography device with high resolution and image quality had a 10x10 cm FOV. Therefore, the diameter of our standard silicon mold was determined as 8 cm to remain within these values. The exposure dose was set at 10 mA-90 kVp.

The anatomic apex of each tooth was used as a reference point to determine the points where temperature measurements would be performed. Images were taken by CBCT and exported to the Carestream CS 3D Imaging Software (Atlanta, GA). This software was used for measuring distances between the inner dentin and the external cementum at 9 points in the horizontal section. These sections were obtained from the root's buccal, mesiolingual, and distolingual regions at 2, 7, and 12 mm levels toward the coronal section from the apex. One hundred teeth with the closest dentin thickness out of one hundred and fifty measured teeth were included in the study to standardize the measurements of temperature changes on the external root surface (Fig. 1) (Table 1).

The teeth were randomly divided into five groups with different root canal filling techniques, with 20 teeth in each group. The tooth root canals were filled using AH Plus (Dentsply, DeTrey, Konstanz, Germany). The experimental groups were as follows;

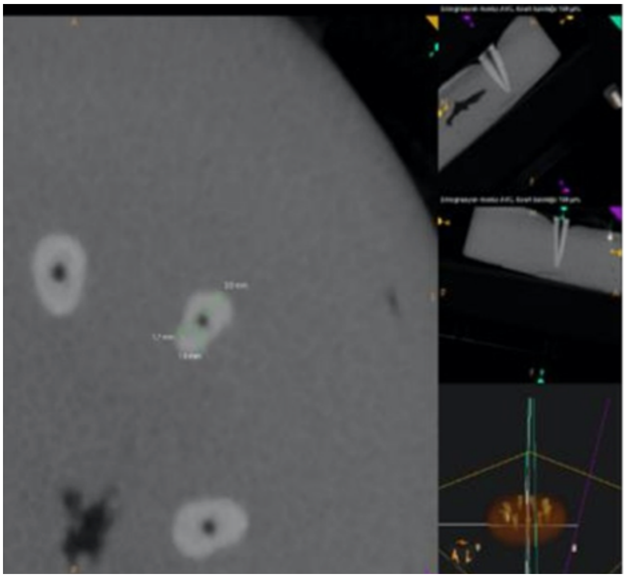


Fig. 1. Measuring the distances between inner dentin and outer cementum from a total of 9 points with CBCT.

Group 1: Cold Lateral Condensation Technique,

Group 2: Warm Vertical Condensation Technique,

Group 3: Continuous-Wave Obturation Technique,

Group 4: Thermoplastic Injection Technique,

Group 5: Carrier-Based Obturation Technique.

Group 1 (Cold Lateral Condensation Technique): The root canals were obturated by cold lateral condensation with #30/0.02 (Pearl-Endo, Pearl Dent Co. Ltd., Ho Chi Minh City, Vietnam) master cones and #15/0.02 (Pearl-Endo, Pearl Dent Co. Ltd., Ho Chi Minh City, Vietnam) auxiliary gutta-percha cones placed in the space opened with #20/0.02 (Golden Star Medical, Shenzhen, China) spreaders. Afterward, gutta-percha was condensed vertically in the coronal third region of the root canal with a suitable plugger type.

Group 2 (Warm Vertical Condensation Technique): A ProTaper Next X3 master cone (Dentsply Maillefer, Tulsa, OK, USA) was placed 1-2 mm from the apical foramen by feeling tug-back to prevent gutta-percha extrusion during condensation with the suitable pluggers. After this stage, the gutta-percha in the coronal 3-4 mm of the root canal was removed from the canal using a heat-carrying device, and vertical condensation was carried out using the pluggers sequentially. The root canal's remaining part was filled with heat application by transporting the gutta-percha pieces cut into 2-3 mm lengths into the root canal.

Group 3 (Continuous-Wave Obturation Technique): The root canals were obturated with the continuous-wave obturation technique using the Elements Free Obturation System (SybronEndo/Kerr Endodontics, Orange, CA, USA). A Buchanan heat plugger (SybronEndo/Kerr Endodontics, Orange, CA, USA), adjusted to be 5-7 mm behind the apical foramen, was selected and attached to the device's down-pack unit. A ProTaper Next X3 master cone (Dentsply Maillefer, Tulsa, OK, USA) was placed 1-2 mm from the apical foramen by feeling tug-back to prevent gutta-percha extrusion during condensation with the pluggers. The apical third was obturated by vertically condensing gutta-percha with the aid of the selected plugger at a constant temperature of 200 °C. Then, vertical condensation was carried out with a suitable cold hand plugger. The disposable gutta-percha cartridge attached to the device's backfill unit was activated with 200 °C heat, and the remaining space inside the root canal was filled with a thermoplastic injection of the warm gutta-percha.

Group 4 (Thermoplastic Injection Technique): The root canals were obturated with the thermoplastic injection technique using the backfill unit of the Elements Free Obturation System device. The tip of the disposable gutta-percha cartridge attached to the device's backfill unit was adjusted to be 3-5 mm shorter than the working length to prevent the uncontrolled extrusion of the molten gutta-percha from apical to periodontal tissues. After the device was operated and activated with a temperature of 200 °C, the cartridge's tip was placed at the predetermined working length, and root canal filling was completed with thermoplastic gutta-percha.

Group 5 (Carrier-Based Obturation Techniques): The root canals were obturated with the carrier-based obturation technique using the ThermaPrep 2 Oven (Dentsply Maillefer, Ballaigues, Switzerland) and ProTaper Next X3 guttacore (Dentsply Maillefer, Ballaigues, Switzerland). The ThermaPrep 2 Oven was brought to a temperature compatible with the ProTaper Next X3 guttacore. Following the light of the ThermaPrep 2 Oven warned that

Table 1. Dentin thickness of one hundred teeth imaged with CBCT according to regions mean and standard deviation values of measurements

n = 150	Buccal Mean ± SD	Mesiolingual Mean ± SD	Distolingual Mean ± SD
Dentin thickness	1.98 ± 0.60 mm	1.64 ± 0.60 mm	1.59 ± 0.54 mm

SD; standard deviation.

the heating process was completed, and the guttacore was placed in the root canal up to the reference point. Excess gutta-percha maintained above the root canal orifice was removed after 2-4 minutes by cutting with a diamond fissure bur.

Measuring Procedure to Detect Temperature Changes

In a Teflon model, 9 holes 1 mm in diameter were drilled at the points corresponding to the 9 points where the CBCT measurements of the teeth were made. K-type thermocouples with a diameter of 1 mm were placed through these holes, and their contact was provided on the tooth's root surface. All root canal filling techniques were performed in a temperature-adjustable water bath (Nüve BM402, Belgium) that can keep the water constant between 5 ˚C and 95 ˚C to imitate the intra-oral temperature. The reservoir of the water bath was filled with distilled water and kept constant at 37 ˚C (Fig. 2). In the present study, thermocouples were first connected to the E-680 series universal input-advanced scanner (Elimko, Emek, Ankara), a temperature-measuring device. Then, the thermocouples were used for temperature measurements during the root canal filling procedure. The temperature measurements obtained during the obturation procedures were recorded with the thermocouples fixed on the tooth's root surface at one-second intervals. One hundred teeth included in 5 groups were filled with different obturation techniques. The temperature increases at 9 different points of each tooth were measured during the procedure. Points T1, T4, and T7, located 2 mm coronal of the apical narrowing, were evaluated as the apical third; points T2, T5, and T8, located 7 mm coronal, were evaluated as the middle third; points T3, T6, and T9, located 12 mm coronal, were evaluated as the coronal third zone. A single value was obtained for each region by taking the average of the highest temperature increase measured by the three thermocouples in each region.

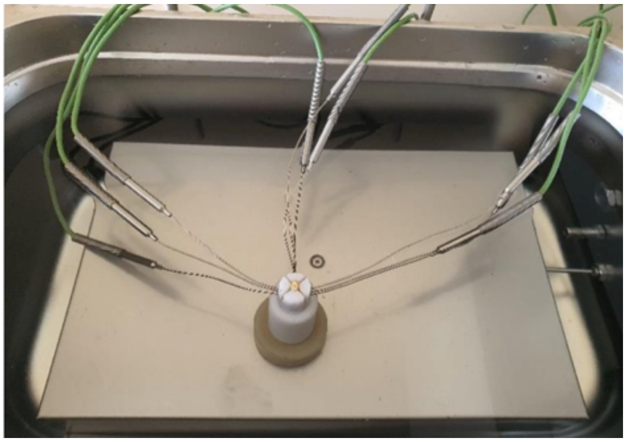


Fig. 2. 9 K-type thermocouple placement on the Teflon model in a 37 ˚C distilled water bath.

Statistical Analysis

The data acquired from the present research were evaluated with the SPSS 22.0 (SPSS Inc., Chicago, Illinois, ABD) package program. The normal distribution analysis of the variables was performed by the Kolmogorov-Smirnov and Shapiro-Wilk tests. Mean, standard deviation, and median values were utilized when presenting descriptive analysis. According to both tests performed to determine whether it had a normal distribution, it was observed that the variables in the apical, middle, and coronal third did not come from the normal distribution. Therefore, the analysis was continued with non-parametric tests. The Kruskal-Wallis H test was conducted to analyze the difference in the group means, and the Mann-Whitney U test was performed to determine which group differed when the difference in the means was statistically significant.

Results

The current study comparatively evaluated the temperature increases detected while applying the 5 obturation techniques. None of the experimental groups reached the critical value of 10 ˚C, the mean temperature increase.

The temperature increase values determined on the external root surface while applying obturation techniques are listed from the highest to the lowest as warm vertical condensation technique, continuous-wave obturation technique, thermoplastic injection technique, carrier-based obturation technique, and cold lateral condensation technique.

As a result, pairwise comparisons performed between the continuous-wave obturation and thermoplastic injection filling techniques, as well as the cold lateral condensation and carrier-based obturation techniques, showed no statistically significant difference ($p > 0.05$). While the warm vertical condensation technique caused the highest temperature increase, the lowest temperature increase values were determined in the cold lateral condensation and carrier-based obturation techniques among all study groups ($p < 0.05$) (Table 2).

Within the scope of the evaluation results performed in terms of root canal regions, the highest temperature increase in all groups was detected in the coronal third regions (Table 3).

Table 2. Temperature (˚C) increases were observed in all groups

Groups (n = 20)	Temperature ˚C	
	Mean ± SD	Median (min-max)
Cold Lateral Condensation Technique	0.27 ± 0.08[a]	0.24 (0.17-0.40)
Warm Vertical Condensation Technique	2.40 ± 0.29[b]	2.37 (1.76-3.21)
Continuous-Wave Obturation Technique	0.89 ± 0.39[c]	0.89 (0.28-1.83)
Thermoplastic Injection Technique	0.39 ± 0.16[c]	0.35 (0.16-0.78)
Carrier-Based Obturation Technique	0.27 ± 0.09[a]	0.26 (0.15-0.48)
p	< 0.001*	

SD; standard deviation. *Kruskal-Wallis. The different letters in each column indicate significant differences between the groups.

Table 3. Difference analysis of temperature (˚C) increases in apical, middle, and coronal third regions according to all groups

Groups (n = 20)	Apical third		Middle third		Coronal third	
	Mean ± SD	Median (min-max)	Mean ± SD	Median (min-max)	Mean ± SD	Median (min-max)
Cold Lateral Condensation Technique	0.22 ± 0.10[a]	0.20 (0.10-0.47)	0.29 ± 0.12[a]	0.30 (0.10-0.60)	0.30 ± 0.13[a]	0.26 (0.13-0.60)
Warm Vertical Condensation Technique	1.57 ± 0.32[b]	1.58 (0.93-2.63)	2.41 ± 0.24[b]	2.35 (2.05-3.75)	3.23 ± 0.53[b]	3.16 (2.23-4.27)
Continuous-Wave Obturation	0.61 ± 0.25[c]	0.60 (0.20-1.20)	0.78 ± 0.45[c]	0.70 (0.20-1.40)	1.29 ± 0.63[a,c]	1.26 (0.33-3.0)
Thermoplastic Injection Technique	0.36 ± 0.16[c]	0.36 (0.13-0.63)	0.32 ± 0.10[a,c]	0.25 (0.15-0.45)	0.49 ± 0.37[a,c]	0.43 (0.13-1.67)
Carrier-Based Obturation Technique	0.24 ± 0.06[a]	0.23 (0.10-0.37)	0.23 ± 0.09[a]	0.20 (0.15-0.50)	0.34 ± 0.17[a]	0.31 (0.13-0.73)
p	<0.001*	<0.001*	<0.001*			

SD; standard deviation. *Kruskal-Wallis. The different letters in each column and row indicate significant differences between the groups. Vertical comparisons are symbolized by lower letters.

Discussion

It is essential to obturate the root canal system more hermetically to keep teeth functioning healthily for a longer time. Therefore, recent obturation techniques have become popular and widely used by clinicians. Filling root canals with warm gutta-percha techniques has led researchers to examine the possible temperature increase during root canal filling (16-19). Certain temperature increases that may occur during the mentioned obturation procedure can be absorbed and distributed by the dentin tissue surrounding the root canal system. This uncontrolled increase that can lead to undesirable complications may subsequently harm the cementum, periodontal ligament, and alveolar bone (19). The current research aimed to compare and evaluate the possibility of damage to support tissues by possible temperature increases on the external root surface while applying the current root canal filling techniques. The findings support the hypothesis that temperature changes occurring on the external surface of the root during the application of traditional and current obturation techniques do not damage periodontal tissues.

Since in vivo conditions were difficult to provide in the present and similar studies (20-22) and it was impossible to perform temperature measurements on the external root surface of the teeth, it was decided to conduct the present study using human teeth extracted in vitro. A study (23) where temperature measurements were performed while applying root canal filling techniques with the warm gutta-percha did not clarify that teeth should be placed in working blocks to imitate intraoral periodontal tissues. Few studies (24,25) were conducted under conditions suitable for the humidity and temperature of the oral environment. The above-mentioned studies evaluated temperature increases during the application of obturation techniques. Furthermore, the temperature of the environment was evaluated at 37 ˚C, which is the heat of the human body, for those studies (24,25). In the current study, temperature measurements were made in a water bath fixed at 37 ˚C, similar to the aforesaid studies, (24,25) by ensuring the full contact of the root surfaces with water to imitate the degree of the intraoral temperature. The teeth included in the current research were placed in a locked model made of Teflon, an insulating material, and were not embedded in any material, considering the research by Venturi et al. (25). In the present study, the thermocouples were fixed on the root surfaces of the teeth by passing them through the holes drilled according to their diameters in the Teflon model. The reason for exposing the root surfaces of the teeth without embedding them in any material can be indicated as the desire to ensure the complete contact of the root's external surface and the thermocouple with the warm water adjusted at 37 °C.

White et al. (26) and Paghdiwala et al. (27) suggested that dentin thickness must be considered in temperature measurements and roots with a low dentin thickness were more prone to temperature increases. In the research by Lee et al. (20), root canal fillings were performed by softening gutta-percha with a System-B heat source, Touch'n Heat device (Analytic Technology, Redmond, WA, USA), and a flame-heated carrier. Temperature changes were measured 2 mm below the cementoenamel junction with K-type thermocouples. According to the results of that study, the highest temperature increase was observed in the mandibular incisors with the lowest dentin thickness. The lowest temperature increase was determined in the maxillary incisors with the highest dentin thickness. The highest temperature increase was detected in the group where the flame-heated carrier was used, whereas the lowest temperature increase was revealed in the group where the System-B heat source was used. Similar to the results of the above-mentioned study, (20) in the present study, dentin thickness plays an essential role in the effect of temperature increases in root canals on periodontal tissues. Therefore, in the current research, CBCT images were taken, and distances between the inner dentin and the external cementum were measured from 9 points of each tooth, and 100 teeth closest to each other formed the experimental groups to standardize the dentin thickness. Thus, more specific measurements can be performed by standardizing the effect of dentin thickness on the temperature increase effects of obturation systems. Similar to Lee et al. (20)'s study results, the current research found the highest temperature increase in the warm vertical condensation group, the technique in which gutta-percha is softened with the device heated in the flame. A lower temperature increase was determined in the continuous-wave obturation technique using the down pack unit of the Elements Free Obturation System, developed based on the System-B heat device. The reason for this temperature difference between the two groups can be explained by the inability to control the heat transmitted to the root canals with the instrument heated in the flame that is used in the warm vertical condensation technique. However, the heat source in the continuous-wave obturation technique constantly gives the same heat at 200 °C.

In the research by Hadis et al. (28), the temperatures of heat carriers were set as follows: the temperature of the E&Q Master (Meta Biomed Co., Chungcheongbuk-do, Korea) was set at 180 °C, the temperature of the E&Q Master was set at 230 °C, and the temperature of System B was set at 200 °C. The temperature changes created by these devices on the external root surface during root canal filling were measured with thermocouples placed 2, 8, and 12 mm coronally from the apical foramen. In all calculated temperatures, the highest temperature increase was observed in the coronal third, while the lowest increase was found in the middle third. In the present study, the down-pack unit of the Elements Free Obturation System set at 200 °C was used as the heat carrier. The thermocouples were placed at a distance of 2, 7, and 12 mm from the apical foramen, almost similar to the aforesaid study (28). Similar to the research by Hadis et al. (28), the reason for the highest temperature increase in the coronal third obtained from all experimental groups in our study can be interpreted as the fact that the highest amount of warm gutta-percha mass was found in this region due to the larger radius created by the flaring form.

A study by Donnermeyer et al. (29) evaluated the continuous-wave obturation, thermoplastic injection, carrier-based obturation using thermafil, and single-cone obturation techniques in terms of the temperature increase obtained from the root canals. Temperature measurements were performed with thermocouples placed in contact with the root canals at a distance of 3, 6, and 9 mm from the apex, and obturation procedures were carried out at 37 °C. In the above-mentioned study, the highest temperature increase among the 4 different techniques was observed in the continuous-wave obturation technique, followed by the thermoplastic injection, carrier-based obturation technique, and single-cone techniques (29). The findings of the aforesaid study are similar to the present study (29). The single-cone technique applied in the study mentioned above and the cold lateral condensation technique applied in our study can be reconciled since heat is not used in both during the application phase. The present study detected no significant difference in the temperature increase between the carrier-based obturation and cold lateral condensation techniques. The reason for this can be indicated as the fact that the heating of gutta-percha is not carried out in the root canals but in an external environment in a special oven and it cools down during transport to the root canal. Furthermore, the rate of gutta-percha covering the core of plastic carriers may be less than the rate applied in other thermoplastic gutta-percha techniques. Therefore, less warm gutta-percha can be found in the root canal in mass. This can be indicated as the reason why less temperature increase occurs in the root canal. Additionally, it was considered that the temperature difference between the groups might be due to differences in the stage of transfer of gutta-percha to the root canal in the root canal filling techniques applied. Although there are studies in the literature evaluating the effect of carrier-based gutta percha obturation techniques using thermafil obturator on the temperature increase in root canals, there is no study using the guttacore obturator. The temperature increase values in this study, in which the Thermafil obturator was used, were found to be similar to our study. The reason for this can be interpreted as the presence of standard gutta percha on the outside of cuttacore and thermafil obturators and the application procedures of the method are the same. It is seen that gutta percha carriers in different materials do not affect the temperature increase.

Conclusion

Compared to the studies on temperature changes during root canal filling procedures in the literature, the current research provides more original clinical conditions reflection and reliable results. We believe that the findings acquired from this research will contribute significantly to dentists' preferences regarding clinical applications and the literature. Moreover, it is thought that current obturation systems, which are increasingly used in endodontic applications, can be used safely without damaging periodontal tissues.

Authorship Contributions: Concept: F.A., R.Z.; Design: F.A.; Supervision: R.Z.; Data: F.A.; Analysis: F.A.; Literature Search: F.A., R.Z; Writing: F.A.; Critical Review: R.Z.

Acknowledgements: The authors would like to express their gratitude to Dr. Ecem Demir Yurtseven for the statistical analysis.

Use of AI for Writing Assistance: Not declared

Source of Funding: This study was supported by the Scientific Research Project Fund of Sivas Cumhuriyet University under the project number DİŞ-241.

Conflict of Interest: None declared.

Ethical Approval: Sivas Cumhuriyet University Non-Interventional Research Ethics Committee approved this study with the decision numbered 2019-09/07 at the meeting held on 11.09.2019.

References

1. Johnson W, Kulid JC, Tay F. Obturation of the cleaned and shaped root canal system. In: Hargreaves KM, Berman LH, editors. Cohen's Pathways of the Pulp. 11th ed. St.Louis: CV Mosby Co; 2016. p. 280–324.
2. Ray HA, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. Int Endod J 1995; 28: 12–8. [CrossRef]
3. Brayton SM, Davis SR, Goldman M. Gutta-percha root canal fillings. An in vitro analysis. I. Oral Surg Oral Med Oral Pathol 1973; 35: 226–31. [CrossRef]
4. Mayo CV, Montgomery S, de Rio C. A computerized method for evaluating root canal morphology. J Endod 1986; 12: 2–7. [CrossRef]
5. Budd CS, Weller RN, Kulild JC. A comparison of thermoplasticized injectable gutta-percha obturation techniques. J Endod 1991; 17: 260–4. [CrossRef]
6. Suciu I, Dimitriu B, Ciocardel M, et al. Evaluation of the sealer/gutta-percha ratio on sets of root section surfaces of some extracted teeth sealed using the cold lateral condensation technique. J Med Life 2021; 14: 337–46. [CrossRef]
7. Chu CH, Lo EC, Cheung GS. Outcome of root canal treatment using Thermafil and cold lateral condensation filling techniques. Int Endod J 2005; 38: 179–85. [CrossRef]
8. Eguchi DS, Peters DD, Hollinger JO, et al. A comparison of the area of the canal space occupied by gutta-percha following four gutta-percha obturation techniques using Procosol sealer. J Endod 1985; 11: 166–75. [CrossRef]
9. Peters DD. Two-year in vitro solubility evaluation of four Gutta-percha sealer obturation techniques. J Endod 1986; 12: 139–45. [CrossRef]
10. Torabinejad M, Skobe Z, Trombly PL, et al. Scanning electron microscopic study of root canal obturation using thermoplasticized gutta-percha. J Endod 1978; 4: 245–50. [CrossRef]
11. Nelson EA, Liewehr FR, West LA. Increased density of gutta-percha using a controlled heat instrument with lateral condensation. J Endod 2000; 26: 748–50. [CrossRef]
12. Gençoğlu N. Comparison of 6 different gutta-percha techniques (part II): Thermafil, JS Quick-Fill, Soft Core, Microseal, System B, and lateral condensation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003; 96: 91–5. [CrossRef]
13. Behnia A, McDonald NJ. In vitro infrared thermographic assessment of root surface temperatures generated by the thermafil plus system. J Endod 2001; 27: 203–5. [CrossRef]
14. Eriksson AR, Albrektsson T. Temperature threshold levels for heat-induced bone tissue injury: A vital-microscopic study in the rabbit. J Prosthet Dent 1983; 50: 101–7. [CrossRef]
15. Matthews LS, Hirsch C. Temperatures measured in human cortical bone when drilling. J Bone Joint Surg Am 1972; 54: 297–308. [CrossRef]
16. Hand RE, Huget EF, Tsakinis PJ. Effects of a warm gutta-percha technique on the lateral periodontium. Oral Surg Oral Med Oral Pathol 1976; 42: 395–401. [CrossRef]
17. Marlin J, Schilder H. Physical properties of gutta-percha when subjected to heat and vertical condensation. Oral

Surg Oral Med Oral Pathol 1973; 36: 872–9. [CrossRef]
18. Barkhordar RA, Goodis HE, Watanabe L, et al. Evaluation of temperature rise on the outer surface of teeth during root canal obturation techniques. Quintessence Int 1990; 21: 585–8.
19. Atrizadeh F, Kennedy J, Zander H. Ankylosis of teeth following thermal injury. J Periodontal Res 1971; 6: 159–67. [CrossRef]
20. Lee FS, Van Cura JE, BeGole E. A comparison of root surface temperatures using different obturation heat sources. J Endod 1998; 24: 617–20. [CrossRef]
21. Beraldo DZ, Pereira KF, Yoshinari FM, et al. Temperature Changes on external root surfaces with the use of several thermoplastic filling techniques. J Endod 2016; 42: 1131–4. [CrossRef]
22. Dimopoulos F, Dervenis K, Gogos C, et al. Temperature rise on the plugger surface of 2 commercially available gutta-percha heating devices. J Endod 2017; 43: 1885–87. [CrossRef]
23. Viapiana R, Guerreiro-Tanomaru JM, Tanomaru-Filho M, et al. Investigation of the effect of sealer use on the heat generated at the external root surface during root canal obturation using warm vertical compaction technique with System B heat source. J Endod 2014; 40: 555–61. [CrossRef]
24. Romero AD, Green DB, Wucherpfennig AL. Heat transfer to the periodontal ligament during root obturation procedures using an in vitro model. J Endod 2000; 26: 85–7. [CrossRef]
25. Venturi M, Pasquantonio G, Falconi M, et al. Temperature change within gutta-percha induced by the System-B Heat Source. Int Endod J 2002; 35: 740–6. [CrossRef]
26. White JM, Goodis HE, Daniels TE. Effects of Nd: YAG laser on pulps. J Lasers Med Sci 1991; 4: 191–200.
27. Paghdiwala AF, Vaidyanathan TK, Paghdiwala MF. Evaluation of erbium:YAG laser radiation of hard dental tissues: Analysis of temperature changes, depth of cuts and structural effects. Scanning Microsc 1993; 7: 989–97.
28. Hadis M, Camilleri J. Characterization of heat resistant hydraulic sealer for warm vertical obturation. Dent Mater 2020; 36: 1183–9. [CrossRef]
29. Donnermeyer D, Schäfer E, Bürklein S. Real-time intracanal temperature measurement during different obturation techniques. J Endod 2018; 44: 1832–6. [CrossRef]